Executing the H21 roadmap

h21

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Executive Summary

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This proposal outlines how the UK gas industry can support the Government in its ambitions to address the 'energy trilemma', by decarbonising the UK energy sector in line with the targets set out in the Climate Change Act 2008. This would be achieved by developing a four to five year funding and delivery strategy which would provide the technical, safety, customer acceptability and cost evidence required to convert the UK gas grid from natural gas to hydrogen, decarbonising the heat sector.

This would be achieved by building on the work presented in the H21 Leeds City Gate Network Innovation Allowance project report (Sections 9 and 10, the next steps and the H21 roadmap respectively). This document recommends funding three extensive work programmes via a series of consecutive Network Innovation Competition annual bids with a combined value of circa £60m. This work programme, coupled with a recommended government led programme for appliances / equipment, would provide the evidence to de-risk the hydrogen for heat pathway.

Decarbonising the UK is an enormous challenge that will require significant innovation and collaboration across all the energy vectors (electric, gas and heat). Decarbonising UK heat, which is predominantly provided by the gas network, is particularly difficult due to the inter-seasonality and established significant customer preference within the UK. Decarbonising the gas network with hydrogen would be a significant contribution to the technical deliverability of the Climate Change Act. Additionally, such a conversion would facilitate the system coupling techno-economic opportunities between the gas and electricity networks. This would unlock the potential of all decarbonisation technologies including renewables, nuclear and district heat.

A decarbonised gas solution to climate change, enabled in tandem to the existing necessity to decarbonise current electricity production, will present customers with the same choice of energy provision as they have today. Furthermore, if a decarbonised gas solution is not possible over 80% of UK gas customers will have their choice of energy options removed. Eventually these customers will have no option other than to make considerable alterations to their homes to accommodate alternatives.

The purpose of this document is to seek support from OFGEM and the Department for Business, Energy and Industrial Strategy (BEIS) to progress with the strategy presented. Specifically the UK gas transportation industry needs senior level confirmation from both OFGEM and BEIS that progressing is encouraged and will be supported.

The three programmes of work would be as follows:

1. **Technical & Strategic Evidence:** An extensive range of projects which will provide the safety case for hydrogen confirming system operability/compatibility. This work, coupled with a government led (or other) programme, is essential to facilitate live trials

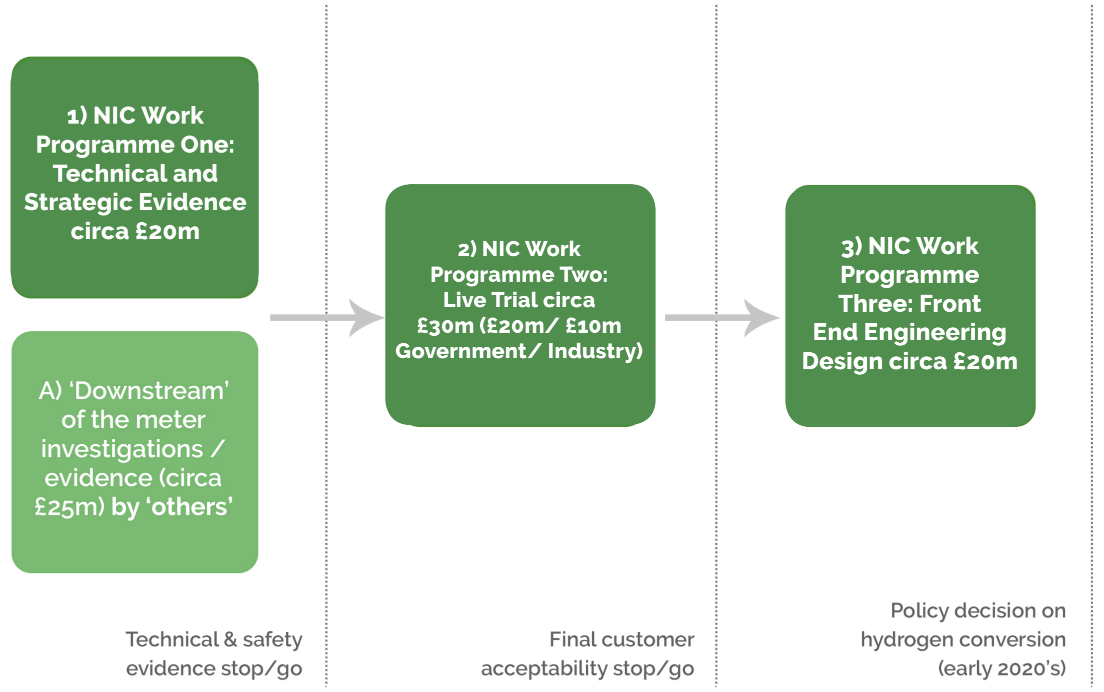
2. **Live Trials:** To provide definitive evidence for hydrogen as a fuel establishing the evidence for customer acceptability

3. **Front End Engineering Design (FEED):** A FEED study will be required to build on the principles identified within the original H21 study incorporating the evidence acquired in the first two NIC work Programmes. The FEED is essential to confirm the economic assessment of UK hydrogen conversion as well as ensuring no delays are encountered should a decision on UK conversion to hydrogen take place

These programmes of work would be managed holistically by a dedicated, high quality H21 programme team.

Delivery Strategy Diagram

The diagram below represents the principle of the proposal and the key delivery objective of each element. In reality each element will overlap slightly (see NIC work programme descriptions).



SECTION 1

Introduction

1. Introduction

The UK, as with most other countries around the world, recognises the challenge of climate change and has resolved, by 2050, to reduce carbon emissions by 80% of their level in 1990. In the UK this is a legal obligation defined under the terms of the Climate Change Act 2008. Climate change is a significant technical, economic, social and business challenge facing the world today and, to date, there has been little investigation or thought leadership into the opportunity to fully decarbonise the UK gas distribution networks.

This proposal outlines how the UK gas industry can support the Government in its ambitions to decarbonise the UK energy sector in line with the targets of the Climate Change Act 2008. Specifically this would be achieved by establishing a four / five year funding and delivery strategy which would provide the technical, safety, customer acceptability and costs evidence required to convert the UK gas grid from natural gas to hydrogen.

This would be achieved by building on the work presented in the H21 Leeds City Gate Network Innovation Allowance project report (Sections 9 and 10, the next steps and the H21 roadmap respectively). This document recommends funding three extensive work programmes via a series of consecutive Network Innovation Competition annual bids with a combined value of circa £60m. This work programme, coupled with a recommended government led programme for appliances / equipment, would provide the evidence to de-risk the hydrogen for heat pathway. The Network Innovation Competition has been identified as the appropriate vehicle for two reasons; the funding is already in place, and the governance criteria is well established and understood.

Decarbonising the UK is an enormous challenge that will require significant innovation and collaboration across all the energy vectors (electric, gas and heat). Decarbonising UK heat, which is predominantly provided by the gas network, is particularly difficult due to the inter-seasonality and established significant customer preference within the UK. Decarbonising the gas network with hydrogen would be a significant contribution to the technical deliverability of the climate change act. Additionally, such a conversion would facilitate the system coupling techno-economic opportunities between the gas and electricity networks. This would unlock the potential of all decarbonisation technologies including renewables, nuclear and district heat.

The purpose of this document is to seek support from OFGEM and the Department for Business, Energy and Industrial Strategy (BEIS) to progress with the strategy presented. Specifically the UK gas transportation industry needs senior level confirmation from both OFGEM and BEIS that progressing is encouraged and will be supported.

1.1 H21 Background

The H21 Leeds City Gate project (referred hereafter as H21) was launched in London on 11 July 2016 and was extremely well received by industry and academia. The project has provided evidence that decarbonisation of the UK gas grid, through 100% hydrogen conversion, is technically possible and economically viable. A conversion of the UK gas grid to hydrogen should be treated as a credible pathway to decarbonisation of heat and subsequently electric generation and transportation.

The H21 project has shown that:

- The gas network has the correct capacity for a conversion to 100% hydrogen
- The network can be converted incrementally with minimal disruption to customers
- A conversion could be undertaken with minimal impact on gas customers bills
- Minimal new energy infrastructure will be required when compared to alternatives
- The existing heat energy demand can be provided by hydrogen generated via steam methane reforming
- Inter-seasonal energy storage can be managed utilising salt cavern storage
- All the technology in the proposal is already in existence

A conversion to 100% hydrogen could be managed with minimal impact in customers' bills (see section 8 & 11 H21 report) due to the natural expenditure profile of the industry. Such a conversion would present significant benefits to the UK including:

- Over 30% of UK emissions come from heating with another 30+% from transportation. As such decarbonising the gas network would decarbonise heating, support decarbonisation of transportation (hydrogen fuelling stations) and support decarbonisation of electric generation (localised and centralised). A UK gas grid conversion to hydrogen has the potential to provide the largest single contribution to the UKs climate change objectives

- Establishing the UK as the world leader in carbon reduction and the first large scale hydrogen economy on earth
- Enhancing system coupling between gas and electricity grids facilitating more unconstrained deployment of renewable energy
- Allowing gas customers to remain on the gas network using energy in the same way they do today
- Providing gas customers with the same choice for energy they have today between gas or electricity
- Removal of the risks of carbon monoxide poisoning
- Increased energy storage for the UK
- Enhanced air quality and the associated air quality improvements
- Significant impact on UK GVA thought jobs creation across the gas supply chain for decades to come

1.2 Lessons of the Past and Present

The UK gas industry is over 200 years old. For the first 150 years the gas used was locally manufactured town gas which contained circa 50% hydrogen with smaller quantities of carbon monoxide and methane. In the early days this was made by distilling coal and, later, oil. Between 1966 and 1977, following the discovery of natural gas in the North Sea, the UK undertook town gas to natural gas conversion.

This was a vast logistical, technological and business challenge to convert over 40million appliances in 14million households. In order to achieve this original conversion programme, extensive industry participation was essential, most significantly by the regulated gas transportation networks (or 12 gas boards of the time) and appliance manufacturing industry. This is what is required today if a natural gas to hydrogen conversion is to be de-risked and subsequently progressed in the UK.

A hydrogen conversion could be executed in the same way the original town gas to natural gas conversion was undertaken. The process will involve minimal disruption for the customers as it will not require the large scale modifications to their property and the way they use energy, which would largely be required for alternative options (for example heat pumps).

Since 2002, the UK has been implementing the Iron Mains Replacement Programme (IMRP), upgrading the majority of its distribution pipes to polyethylene. This is a risk prioritised, HSE mandated, initiative due to complete in 2032. These polyethylene pipes are suitable for transporting 100% hydrogen and have an estimated asset life of between 80 and 100 years.

As with the original conversion from town gas to natural gas, it is vitally important that all evidence is acquired to provide confidence that a hydrogen conversion can take place. This should demonstrate that a conversation would pose only a comparable safety risk to the public as that currently accepted in the use of natural gas today. In the original conversion the gas council established the conversion executive, a team which would oversee the overall conversion process. It also managed various trials / evidence-gathering projects over a period of several years.

1.3 H21 Roadmap – The Urgency

Key parts of the H21 project report are section 9 and 10 'the next steps' and 'the H21 Roadmap' respectively. These sections outline how to move the UK forward to a definitive decision on hydrogen conversion. Calls for the Government to urgently progress H21 to the next steps in line with the H21 roadmap have been made in a range of recent publications including:

- The Climate Change Committee – 'Next Steps for Heat Policy'
- Policy Exchange – 'Too Hot to Handle'
- Report to the Secretary of State for Business, Energy and Industrial Strategy from the Parliamentary Advisory Group on Carbon Capture and Storage – 'Lowest Cost Decarbonisation for the UK: The Critical Role of CCS'

Each of these publications emphasises the need for urgent action by the government today in order to make a credible policy decision by the early 2020's. Failure by government to make clear committed decisions to credible, de-risked pathways for decarbonisation will result in a failure to meet the challenge of the Climate Change Act.

Furthermore, there is a pressing time requirement for the UK gas industry and OFGEM to progress the viability of such a decision to ensure appropriate, no regrets, well understood, funding can be incorporated into GD2 business plans.

It is critical that, over the next five years, all decarbonisation options (hydrogen, electrification of heat, district heat) and their appropriate geographical/end user applications are fully understood. Failure to provide customers with the visibility or understanding of choice could lead to uninformed customer actions and excessive spending on non-optimised alternative strategies.

The next sections of this document outline Northern Gas Network's strategy for executing the H21 roadmap in a series of Network Innovation Competition bids.

SECTION 2

Work Programme Description

2. Work Programme Description

The H21 report has demonstrated that converting the UK gas networks to hydrogen is technically possible. However, in order to make the policy decision required to incrementally convert the UK to hydrogen the report recognises and identifies there is an evidence based programme of physical works required.

This work is estimated to cost £80m to £100m and could be completed over a five year period. Some parts of the H21 roadmap identify work 'downstream' of the customers meter (domestic, commercial or industrial) predominately associated with appliance and equipment development.

This work would need to be undertaken by the appliance and equipment manufacturing industry. This industry is now highly fragmented and it is considered appropriate that a work programme in this area would need both government funding and leadership. The UK gas transportation sector would not be well placed to manage and undertake this work from both a logistics point of view (fragmented small players market) and expertise point of view unless supported by government. As a result, 'downstream of the meter' work has been removed from the scope of this proposal and it is recommended that the UK government establishes a programme to undertake this work. This work has been estimated at circa £25m over the overall roadmap.

The majority of work and funding can be segmented into three sections (referred hereafter as NIC work programmes 1, 2 & 3 respectively). It is anticipated that each NIC work programme will cost circa £20m to £25m. The areas of work are:

1. **Technical & Strategic Evidence**: An extensive range of projects which will **provide the safety case for hydrogen** confirming system operability/compatibility. This work, coupled with a government led (or other) programme, is essential to facilitate live trials
2. **Live Trials:** To provide definitive evidence for hydrogen as a fuel establishing the evidence for **customer acceptability**
3. **Front End Engineering Design (FEED)**: A FEED study will be required to build on the principles identified within the original H21 study incorporating the evidence acquired in the first two NIC work Programmes. **The FEED is essential to confirm the economic assessment of UK hydrogen conversion** as well as ensuring no delays are encountered should a decision on UK conversion to hydrogen take place

Delivery: H21 Programme Team

A programme of this scale requires commitment, high levels of expertise and a dedicated team to develop, drive and coordinate the results. Without a dedicated team in place delivery will be significantly delayed and inadequately executed. This will result in delays in the ability to commit to a UK wide hydrogen conversion programme in line with the targets identified within the Climate Change Act. This team would be funded as part of each work package, growing in scale to meet the objectives of the overall programme.

It is also vitally important that this programme team retains a close link with BEIS to ensure evidence is progressed and developed in line with policy, strategy and any potential government funded programme in the appliance/equipment side of the gas industry (downstream of the meter). Equally important will be the team's relationship with OFGEM, who will be involved at every stage so that the regulatory framework is supportive of the project (see governance, section 3.0).

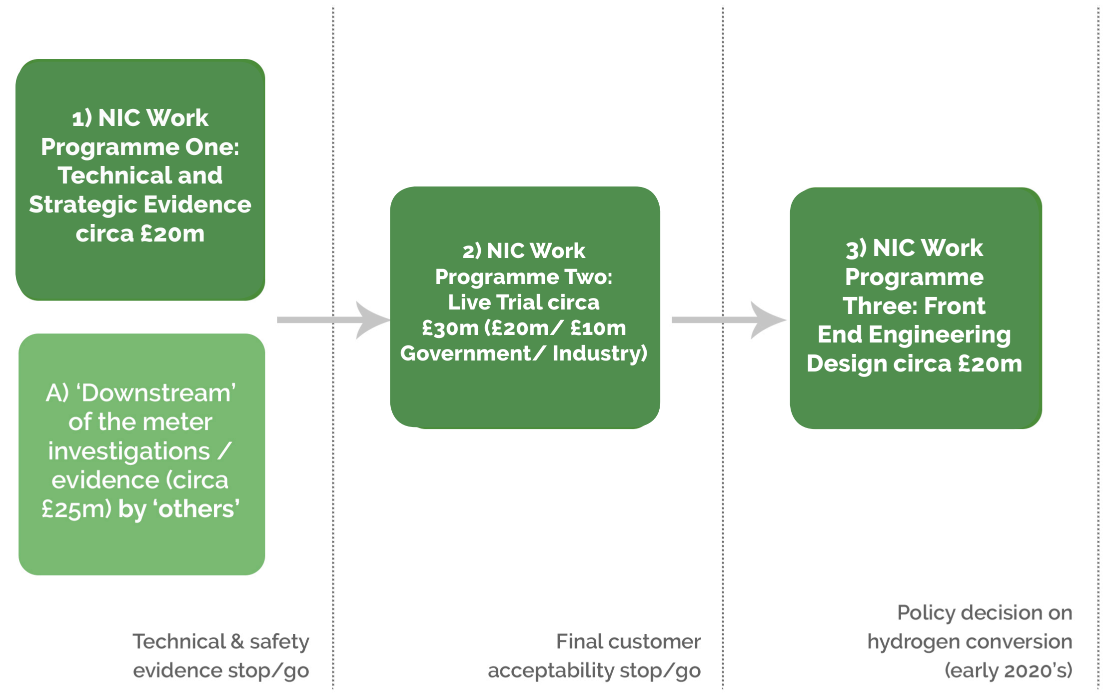
Table 2.1 and diagram 2.1 below provide an overview of the programme delivery timelines as well as the elements of the H21 roadmap specific to each NIC programme of works.

Table 2.1 NIC Package and Associated Timescales

NIC Bid Year	Work packages (full description see section 10 of the H21 report)	2017	2018	2019	2020	2021	2022
2017: Developing the technical evidence required for the hydrogen safety case	1. Pressure reduction - x6 projects	Bid prep					
	2. Below seven bar mains considerations						
	3. Industrial and commercial Appliances	Not included - undertaken by others					
	4. Domestic Considerations						
	5. Multi accupancy buildings						
	6. Blending						
	7. Odourisation/ Gas detection						
	8. Technical standards						
	9. Regulation						
	12. Carbon capture and storage						
	13. Transportation						
	14. Electrification						
	15. Unconventional gas						
	16. UK wide development strategy						
2018 - Trials	10. Public perception		Bid prep				
	11. Appliance demonstration / Field trials		Bid prep				
2019	Front end engineering design study			Bid prep			

Diagram 2.1 Delivery Strategy Diagram

The diagram below represents the principle of the proposal and the key delivery objective of each element. In reality each element will overlap slightly (see NIC work programme descriptions).



2.1 NIC Work Programme One: Technical and Strategic Evidence

The H21 report has shown the UK gas network is capable of transporting 100% hydrogen whilst maintaining the current energy security parameters for peak heat. It has also demonstrated that the technology to achieve such a conversion is available and evident across the world today. However, a conversion to hydrogen can only be undertaken if the safety case for conversion is robustly tested.

Ultimately, as was the case with the original conversion from town gas to natural gas between 1966 and 1977, the safety case as well as customer acceptability can only be demonstrated via a live trial in a small area. To enable such a trial to be conducted in a methodical and safe manner, a programme of extensive testing needs to be undertaken on the below seven bar gas distribution network assets.

The H21 roadmap has provided an outline of the work programme that is required to provide this evidence. The objective is to confirm that transportation and use of 100% hydrogen can be managed to present a comparable risk to that currently presented by natural gas. There are three principle purposes to these projects:

1. **To provide the safety based evidence for asset compatibility and quantitative risk analysis (vs natural gas) for the below seven bar distribution network**. This, coupled with the downstream of the meter evidence (recommended to be undertaken by government), would provide the safety case evidence to progress towards a live trial
2. **To confirm the H21 Leeds City gate feasibility assumptions regarding hydrogen transportation were accurate.** Simplistically, whether hydrogen will distribute thought the UK below seven bar gas network in the volumes and at the velocities indicated in the H21 Leeds City Gate study. This is critical to ensuring security of supply and safe systems of operation for a subsequent live trial and also for modelling a UK wide incremental role out of hydrogen
3. **To confirm the method for defining annual demand for the area of conversion within the original H21 Leeds city gate study (The office of National Statistics data adjusted by degree day's assessment) is accurate.** This is critical for modelling a UK wide incremental rollout of hydrogen

In addition to the safety based considerations this section of work will also consider the strategic rollout impact for a future hydrogen conversion. This will involve the following principle activities:

1. **Working with all gas distribution networks across the UK to determine appropriate conversion strategies.** This would entail expanding the modelling for H21 to demonstrate detailed conversion strategies area by area and city by city
2. **Determine the hydrogen transmission system (including compression), storage and hydrogen production system requirements.** To consider against a range of incremental conversion strategies working alongside government policy teams. This would be vital to support NIC work programme 3 (FEED) and needs to be addressed as part of this work package so as to not embed delays in delivery. This is also critical to technically and economically understand potential options that could imact on GD2 / 3 price control periods
3. **Working with a range of external stakeholders to effectively model projections and timelines for hydrogen use in vehicles, centralised/decentralised power generation and large scale industrial decarbonisation timelines.** These projections are vital to enable robust gas distribution network modelling for energy supply and demand forecasts in converted areas. Critically this is required to determine the associated hydrogen production and storage requirements when considered against a growing based load. This would be vital to support NIC work programme 3 (FEED) and needs to be addressed as part of this work package so as to not embed delays in delivery.

The strategic work is essential to understand holistic costs and network impacts for different hydrogen conversion scenarios. It will be a critical source of information to inform both the FEED study (see section 3) and will also help to define what the UK policy may look like. Additionally it will allow networks to consider requirements that will be relevant for GD2/GD3, dependent on ultimate government direction.

2.1.1 Key Objectives

- To provide the necessary safety case-based evidence required to move towards a 100% hydrogen live trial
- To provide a comprehensive UK wide evidence base supporting different network conversion strategies to facilitate GD2/3 business plan projections, government policy direction and the FEED study identified in NIC work package 3
- To demonstrate customer appetite for alternative forms of gas to ensure energy security

2.1.2 Funding

Funding for a programme of this scale has been estimated to be in the region of £20m to £25m. It is anticipated that the full £18m of available NIC funds will be requested with the remainder provided by the UK gas industry and, where appropriate, leveraging of additional funds from local authorities where there is a significant regional benefit.

More detailed costs will be provided as part of the 2017 NIC bid submission but it should be noted that firm costs will only be established once the programme team is in place and detailed scopes are produced for each project.

2.1.3 Stakeholders

Stakeholders for this stage will be extensive in terms of both execution of a wide and varied programme of work and knowledge dissemination/compilation. This will be managed by the H21 programme team.

Execution is anticipated to involve a range of small, medium and large delivery partners with significant involvement across academia. Extensive liaison will be required with local authorities and across the UK Gas Distribution Network Operators (GDNs). Additionally a steering board comprising, as a minimum, the GDNs, OFGEM, the Health and Safety Executive (HSE) and BEIS will be required to ensure that the work is progressing in line with policy and regulatory considerations (see governance section 3,0).

Additionally a creative public engagement programme will be required to educate and inform the public as well as enabling identification of a community in which to undertake the live trials identified in NIC work programme two.

Finally close relations will need to be established with the upstream hydrogen manufacturers to ensure gas quality standards and system requirements for NIC work programme two are developed in a practical and deliverable manner.

2.2 NIC Work Programme Two: Live Trials

This programme of work is the definitive evidence required to support a policy decision to convert the UK gas grid to hydrogen. In the original conversion from town gas to natural gas, Canvey Island and Burton-on-Trent were converted in live trials prior to the subsequent policy decision. This served two significant purposes:

1. It allowed the gas industry to understand the logistical challenges associated with conversion of appliances and equipment, this also helped confirm conversion cost and timeline estimates
2. It provided government with the consumer acceptability evidence required to provide confidence that a policy decision would be positively accepted, in the main, by the British public

The work undertaken as part of NIC work programme one will provide the safety and system evidence that live trials can commence. This, coupled with the work undertaken downstream of the meter (preferably funded and led by government), will provide the end-to-end system evidence for live trials.

As part of work package one the H21 programme team will work alongside a downstream government led team to identify and work with relevant communities in preparation for live trials commencing.

NB: If a recommended government led 'downstream of the meter' programme of work has not been undertaken this proposal would not progress further from NIC work programme one until a time when such work had been undertaken.

2.2.1 Section Objectives

- To provide end-to-end system evidence for 100% hydrogen grid conversion
- To provide comprehensive customer acceptance evidence to support a hydrogen conversion UK policy decision

2.2.2 Funding

A live trial is estimated to cost up to £30m. It is anticipated that the full £18m of available NIC funds will be requested with the remainder provided by the UK gas industry and UK government. This stage will require the co-ordination of both NIC work package one and the government led 'downstream of the meter' work.

Extensive planning for this work will be undertaken by the H21 programme team as part of NIC work package one. This is essential to ensure a transition to live trials that is both complementary to any government 'downstream of the meter' work as well as being able to execute the trial in a timely manner.

2.2.3 Stakeholders

In order to undertake live trials extensive stakeholder engagement will be required building on the work undertaken in NIC work programme one. The following stakeholders would be heavily involved as a minimum, managed by the H21 programme team:

- **The live trial community:** Vital as these trials will require changes of appliances in their homes
- **The appliance manufacturing industry:** Who will provide the appropriate appliance upgrades
- **Local Authorities**
- **The hydrogen production companies:** To provide a secure supply of hydrogen to the customers
- **The shippers:** To understand the billing requirement of the system
- **The HSE:** To allow the trail to commence
- **The gas distribution networks:** To provide access to the network to convert to hydrogen and expertise
- **The gas-safe certified plumbing community:** To undertake the conversion within the home
- **The media:** Media coverage will be inevitable and will also be critical to support public engagement and awareness

As with NIC work programme one the steering board comprising, as a minimum, the GDNs, OFGEM the HSE and BEIS will be required to ensure the work is progressing in line with policy and regulatory considerations.

2.3 NIC Work Programme Three: Front End Engineering Design (FEED)

The FEED is engineering which comes after the conceptual design or feasibility study. It focuses the technical requirements, establishes a price for the execution phase of the project and evaluates the potential risks. In the case of H21 it will be essential to build on the work of the original H21 Leeds City Gate study and combine this with the incremental learning established as part of NIC work programmes one and two.

The FEED will reflect all of the Government's heat decarbonisation aspirations coupled with the technical practicalities of delivery. A FEED for larger sized projects usually takes around 1 to 2 years to complete and will provide a comprehensive starting point for conversion. This would subsequently be developed into a detailed design once a policy decision to convert has been made by central government. It will present the UK Government with a robust platform from which to expedite execution of a UK conversion plan.

The FEED would be managed by the H21 programme team and would be tendered to a main works contractor for delivery. The FEED study also provides the opportunity to engage all stakeholders across the Hydrogen system supply chain in readiness for any subsequent policy decision to convert.

2.3.1 Section Objectives

- To provide robust costs on conversion strategies
- To ensure timely execution of a policy decision to convert to hydrogen

2.3.2 Funding

Funding for the FEED is anticipated to cost between £15m and £20m. It is anticipated that the full £18m of available NIC funds will be requested with the remainder provided by the UK gas industry and UK government. This stage will require co-ordination of all the results from NIC work programmes 1 and 2. It will also require close liaison with BEIS to ensure the initial conversion design considerer the full UK perspective and decarbonisation ambitions.

Costs are based on the work presented in the H21 Leeds City Gate report section 9.

2.2.3 Stakeholders

As with any FEED study, engagement with the correct stakeholders is critical to ensuring development from feasibility stage (i.e. the original H21 Leeds City Gate report) through FEED meets with the aspirations of the client. In this case the 'client' could be considered to be the UK Government and local authorities as the FEED study should be the last part of the pre-works required prior to a government policy decision in support of conversion.

SECTION 3

Governance and Execution

3.0 Governance and Execution

3.1 The Steering Board

As these three programmes of work will be funded by consecutive years of NIC bids the detailed governance arrangements will be presented in each bid as per the NIC criteria. By default this also provides the appropriate terms of reference for stop/go decision making in terms of progression of the respective programmes of work.

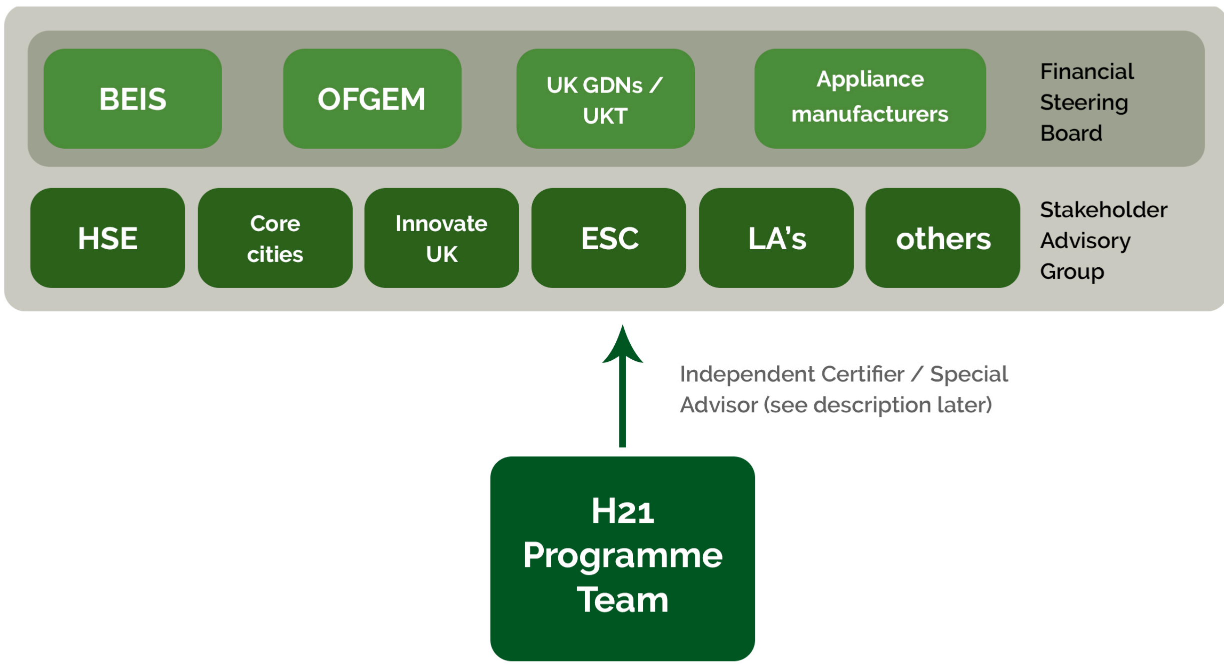
In principle it is anticipated that these three NIC programmes of work will be governed by a establishment of a financial steering board. This board should include representation of BEIS, OFGEM, representatives from the UK gas transportation industry and the appliance manufacturing industry.

This board would undertake activities including - but not limited to - receiving and reviewing bi-monthly reports from the H21 programme team, sign-on to procurement strategies, and monitoring progress against the committed spends and programme.

A wider stakeholder advisory board should be established meeting, every six months. The purpose of this group would be to disseminate knowledge from (and potentially to) the H21 programme team ensuring wider industry and local authority support. These two groups are shown pictorially below with examples of key participants on the stakeholder advisory board.

As part of the annual review this programme board would be able to terminate the programmes of work should insurmountable 'show stoppers' to hydrogen conversion be encountered. This is considered highly unlikely.

H21 programme team governance



3.2 Delivery - H21 Programme Team

As previously discussed, the delivery of this complex work programme requires a dedicated high quality programme team. This is the same methodology as that adopted for the original town gas to natural gas conversion by way of establishment of 'the conversion executive'.

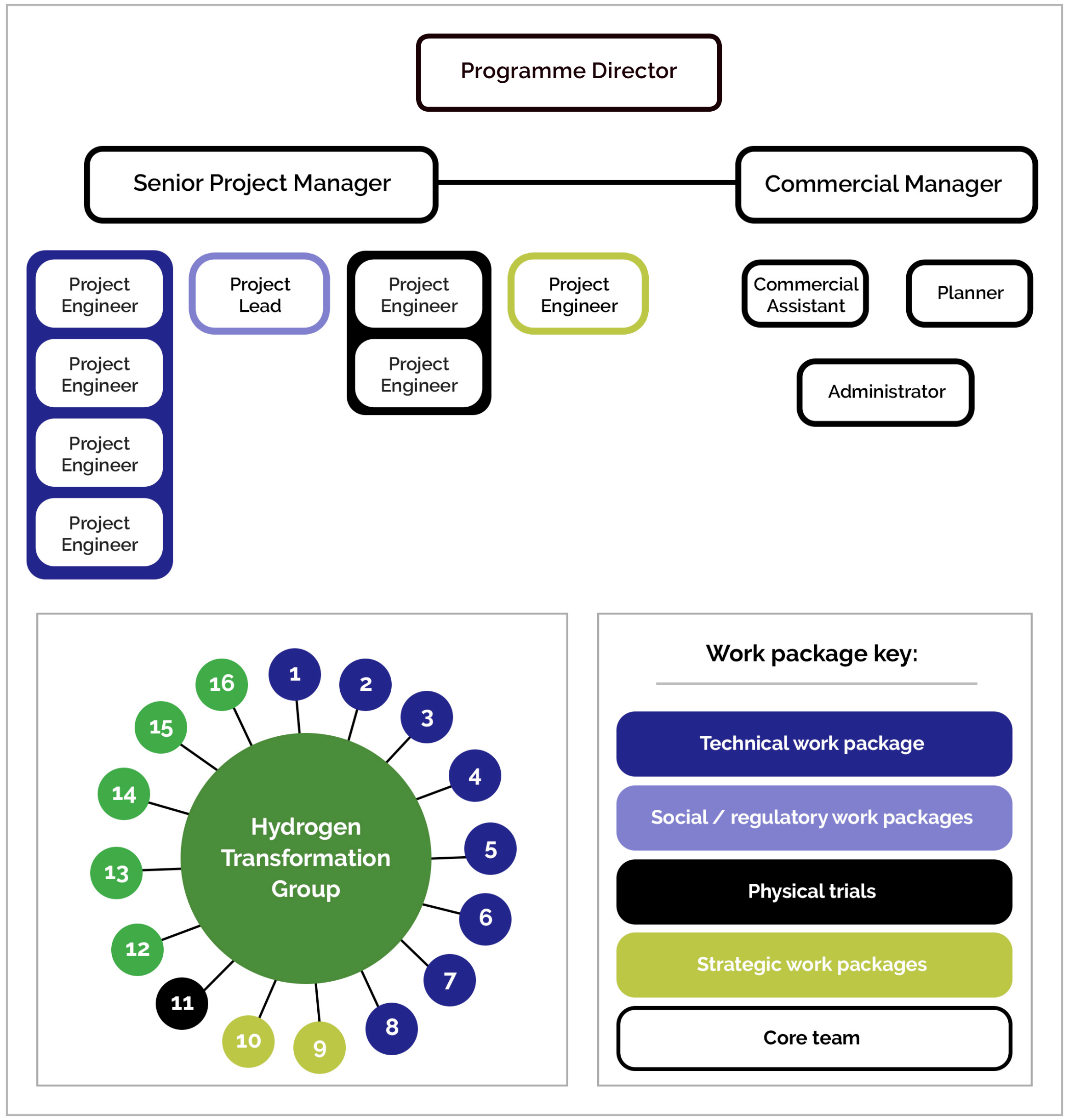
This is a highly technical work programme requiring a technically competent core team, each of the individual elements within the H21 roadmap has provision for the necessary social / economic skills as required (for example work package 10 'public perception (see table 2.1)).

The H21 roadmap has provided a structure for this group covering all the work packages (shown diagrammatically below – see section 10 of the H21 report for more detail). It is recommended that a 'core team' be established which has complete autonomy from any particular organisation to ensure impartiality, trust and development of a strategy that is entirely in the interests of the UK.

Other members of the H21 programme team should be provided by the UK gas industry as competitively secured secondments (i.e. the industry puts forward individuals to be interviewed and accepted by the programme director).

Additionally it is strongly recommended that this group be located at Leeds to ensure on-going local support and the continued 'Northern Powerhouse' principles of the H21 strategy. An example of the H21 programme team structure has been provided below and is taken from section 10 of the H21 report.

Diagram 3.2 H21 Programme Team Diagram



3.3 The Role of the Special Advisor / Independent Certifier

Consideration should be given to the appointment of a full time 'special advisor / independent certifier' who can provide expert support to the H21 programme team as well as an impartial view on progress and effectiveness back to the steering board and wider stakeholders.

This individual, who should report direct to the steering board, will have the following core responsibilities:

- To provide independent, expert opinion to all stakeholders
- To provide a separate independent validation report to the financial steering board
- To work across all the stakeholders of the financial steering group
- To work across all stakeholders ensuring knowledge dissemination both to and from the HTG
- To work across gas distribution companies providing specific advice on conversion strategies on different city gas grids. This will ensure:
    - sharing of best practice
    - validation of proposed conversion plans and their financing requirements for GD2
    - supply of information back to the HTG to support UK strategy i.e. Hydrogen Transmission system development
- Supporting the BEIS policy teams with both technical advice (on hydrogen and wider gas grid strategy for example bio-SNG, BIO methane, decommissioning etc)
- To support the Programme Director for the HTG in knowledge dissemination and technical expertise
- To challenge the HTG strategy (for example procurement, progress etc)
- To promote the work of the HTG locally and internationally

SECTION 4

Value for Money for Gas Customers

4. Value for Money for Gas Customers

To define the benefits of a UK gas conversion to hydrogen in the context of value for money for gas customers, we must consider both drivers for change: the Climate Change Act, and the impact of alternative solutions.

4.1 The Commitment to the Climate Change Act 2008

It is clear that the Climate Change Act has cross party support which is echoed internationally in all developed nations across the globe and is further enhanced by the Paris Agreement. Continuing to use natural gas as the UK does today will prevent the UK meeting the challenge of the Climate Change Act.

In short, if the UK gas industry cannot provide a large scale solution to climate change that **includes the total decarbonisation of the gas grid,** it will, at some point, need to be 'turned off' or as a minimum its use significantly curtailed. Eighty percent of energy customers in the UK use natural gas for heating cooking and hot water. If the industry was 'turned off' customers would have to make considerable alterations to their property and the way they use energy.

Meeting the challenge of the Climate Change Act is a UK wide challenge and the solution(s) which are ultimately adopted will cost significant amounts of money, funded either through energy bills or taxes. This means that finding the most economical solution to climate change is in the interests of all British customers. Furthermore, a solution which has low impact on the energy supply chain will keep customer impact to a minimum.

A recent report by KPMG, funded by the Gas Futures Group, suggested that converting to hydrogen could be £150bn to £200bn cheaper than an all-electrical alternative. It also concluded that hydrogen conversion could be achieved with minimal hassle for the customer compared to the alternatives and could ultimately be far more technically achievable.

4.2 Expenditure Profile of the Gas Industry – No Bill Impact

Careful design and consideration of UK hydrogen conversion strategies could be managed in order to have almost no impact on customers' bills. This would be achieved by timing the onset of hydrogen conversion with the end of the IMRP, effectively meaning one cost replaces another. Importantly, as with all decarbonisation pathways, costs will be kept lower in conjunction with increasing energy efficiency measures in the home. Alternative strategies will almost definitely have a larger impact on customers' bills as they are likely to cost considerably more and the customer will have to pay for changes to their appliances. This was also highlighted in the KPMG 2050 Energy Scenarios report.

If a decarbonised gas grid solution can be realised in the UK it will also remove the possibilities of the high economic impact of decommissioning the UK gas grid (estimated recently at over £20bn) and the write-off costs associated with what would become a stranded asset.

4.3 Choice for Customers

A decarbonised gas solution to climate change, enabled in tandem to the existing necessity to decarbonise current electricity production, will present customers with the same choice of energy provision as they have today. Furthermore, if a decarbonised gas solution is not possible over 80% of UK gas customers will have their choice of energy options removed and will eventually be forced to make considerable alterations to their homes to accommodate alternatives.

4.4 Improved Health Benefits

A conversion to hydrogen would provide demonstrable benefits to health across the UK. Significant improvements in air quality across UK cities and the total removal of risk from carbon monoxide poisoning (which is chemically impossible through a 100% hydrogen gas network) are two of the most significant health benefits.

4.5 Impact on GVA

Conversion of the UK gas grid to hydrogen, incrementally over time, will provide hundreds of thousands of jobs across the gas supply chain for decades to come. This would be alongside traditional value added benefits such as skills and innovation.

Finally jobs in the North Sea would be retained if hydrogen conversion was to take place. These would be associated with the carbon capture and storage infrastructure essential for a UK gas grid decarbonisation strategy to be developed.

SECTION 5

Conclusion

5. Conclusion

This proposal outlines a credible strategy to enable the UK gas Industry to support the Government in its ambitions to decarbonise the UK energy sector in line with the targets of the Climate Change Act. This would be achieved by establishing a four / five year funding and delivery programme which would provide the technical, safety, customer acceptability and costs evidence required to convert the UK gas grid from natural gas to hydrogen.

This would be achieved by building on the work presented in the H21 Leeds City Gate Network Innovation Allowance project report (Sections 9 and 10, the next steps and the H21 roadmap respectively). This document recommends funding three extensive work programmes via a series of consecutive Network Innovation Competition annual bids with a combined value of circa £60m. This work programme, coupled with a recommended government led programme for appliances / equipment, would provide the evidence to de-risk the hydrogen for heat pathway.

The purpose of this document is to seek support from OFGEM and the Department for Business, Energy and Industrial Strategy (BEIS) to progress with the strategy presented. Specifically the UK gas transportation industry needs senior level confirmation from both OFGEM and BEIS that progressing is encouraged and will be supported.

The programme, recommended to be managed by a H21 programme team, have been split into 3 clear 'NIC work Programmes' as defined below:

The three programmes of work would be as follows:

1. Technical & Strategic Evidence: An extensive range of projects which will provide the safety case for hydrogen confirming system operability/compatibility. This work, coupled with a government led (or other) programme, is essential to facilitate live trials.

2. Live Trials: To provide definitive evidence for hydrogen as a fuel establishing the evidence for **customer acceptability.**

3. Front End Engineering Design (FEED): A FEED study will be required to build on the principles identified within the original H21 study incorporating the evidence acquired in the first two NIC work Programmes. **The FEED is essential to confirm the economic assessment of UK hydrogen conversion** as well as ensuring no delays are encountered should a decision on UK conversion to hydrogen take place.

In order to progress with the proposal set out in this document it is recommended that 'support in principle' is provided to the gas industry by OFGEM and BEIS. For this proposal to be progressed it needs support from all the UK gas industry GDNs and UKT. Collaboration for such an extensive, long term future focused, programme of works will be much easier to galvanise with a clear indication from OFGEM & BEIS.

Any subsequent NIC bids would still need to provide evidence of value for money and deliverability as per the requirements laid out within the NIC governance document although the expert panel may need to take a much wider long term view of the benefits to UK gas customers than those typically presented in annual NIC discussions to date.

Appendix 2

H21 Leeds City Gate NIA Project Report: Executive Summary

Executive Summary

The UK, as with most other countries around the world, recognises the importance of meeting the challenge of climate change and has resolved, by 2050, to reduce carbon emissions by 80% of the level in 1990 under the terms of the Climate Change Act. This is the biggest energy challenge facing the world today although, to date, there has been little investigation or thought leadership around the opportunity to decarbonise the UK distribution gas network by specifically focusing on large cities.

Even natural gas (predominantly methane), the lowest carbon dioxide emitter per unit of energy of any fossil fuel, produces about 180 gm/kWh CO_2 equivalent whereas hydrogen emits zero (at the point of use). The change over from natural gas to hydrogen has the potential to provide a very deep carbon emission reduction. The true carbon footprint of hydrogen depends on its source. For example, grid power electrolysis has very high emissions whereas hydrogen made from stripping the carbon atom from natural gas has about 50 gm/kWh CO_2 equivalent including indirect emissions, a large reduction over the existing unabated natural gas fuel. Renewable-based electrolysis could be used, but for the foreseeable future the required quantities do not look realistic.

This report suggests that we can significantly decarbonise parts of the existing gas network at minimal additional cost to consumers. This would significantly contribute to the UK's 2050 and Paris Agreement commitments, remove the risks of carbon monoxide poisoning, increase energy storage, potentially remove air pollution from vehicles, and enable new product development and innovation for manufacturing and industrial businesses.

The UK gas industry is over 200 years old. For the first 150 years the gas used was locally manufactured town gas which contained circa 50% hydrogen with smaller quantities of carbon monoxide and methane. In the early days this was made by distilling coal and, later, oil. Following the initial discovery of natural gas in the North Sea, made up predominantly of methane, during the 1960/70s the UK undertook a nationwide gas conversion programme converting 40 million appliances, reaching a peak of 2.3 million per year. Over 80% of the UK population now use this gas network for heating and cooking. A hydrogen conversion would follow a similar process to the original town gas to natural gas conversion undertaken so successfully and within living memory. The process will involve minimal disruption for the customer (domestic or commercial) and require no large scale modifications to their property.

Since 2002, the UK has been undertaking the Iron Mains Replacement Programme (IMRP), upgrading the majority of its distribution pipes to polyethylene. This is a risk prioritised, Health and Safety Executive mandated initiative due to complete in 2032. These polyethylene pipes are considered to be suitable for transporting 100% hydrogen.

The H21 Leeds City Gate project is a study with the aim of determining the feasibility, from both a technical and economic viewpoint, of converting the existing natural gas network in Leeds, one of the largest UK cities, to 100% hydrogen.

The project has been designed to minimise disruption for existing customers, and to deliver heat at the same cost as current natural gas to customers.

The project has shown that:

- The gas network has the correct capacity for such a conversion
- It can be converted incrementally with minimal disruption to customers
- Minimal new energy infrastructure will be required compared to alternatives
- The existing heat demand for Leeds can be met via steam methane reforming and salt cavern storage using technology in use around the world today

The project has provided costs for the scheme and has modelled these costs in a regulatory finance model.

In addition, the availability of low-cost bulk hydrogen in a gas network could revolutionise the potential for hydrogen vehicles and, via fuel cells, support a decentralised model of combined heat and power and localised power generation.

The Results

The results of the Project are as follows:

Demand vs. Supply (Section 2)

The energy demands calculated for the area of conversion are:

1. Average yearly gas demand = 678 MW (derived from DECC data)
2. Maximum peak yearly demand = 732 MW (temperature corrected DECC data)
3. Maximum peak hour demand = 3,180 MW (NGN 1 in 20 peak hour demand)
4. Peak day average demand = 2,067 MW (derived from NGN 1 in 20 peak hour demand design parameter)
5. Total average yearly demand = 5.9 TWh
6. Total peak year demand = 6.4 TWh

This demand would be serviced by the following hydrogen production and storage facilities: Hydrogen production capacity of 1,025 MW_{HHV} (305,000 Sm^3/h) provided by four Steam Methane Reformers (SMRs) located at Teesside, fitted with 90% carbon dioxide capture. This CO_2 is then compressed to 140 bar and assumed to be exported 'over the fence' to permanent sequestration deep under the North Sea. Such hydrogen production at large scale is fully proven, with worldwide production standing at about 50 million tonnes per annum compared to 0.15 million tonnes per annum for the proposed area of conversion.

Additional intraday storage, which together with the SMRs and inter-seasonal storage, will supply a maximum 1 in 20 peak hour demand of 3,180 MW_{HHV}. This will be in the form of salt cavern storage located at Teesside, some which may be repurposed from already existing caverns.

Inter-seasonal storage of 702,720 MWh (40 days of maximum average daily demand (coldest year), 209 million Sm^3 hydrogen). This will be in the form of salt cavern storage located on the East Humber coast.

A Hydrogen Transmission System (HTS) will connect the SMRs and salt caverns to the proposed area of conversion (Leeds) and will be capable of transporting at least the peak supply requirement of 3,180 MW.

Gas Network Capacity (Section 3)

Both the Medium Pressure (MP) and Low Pressure (LP) gas distribution networks within the area of conversion have been modelled for hydrogen conversion using the network analysis software and data currently used by Northern Gas Networks. The conclusion of this modelling is that the gas networks have sufficient capacity to convert to 100% hydrogen with relatively minor upgrades.

Gas Network Conversion (Section 4)

It is possible for the existing gas network to be segmented and converted from natural gas to hydrogen incrementally through the summer months over a three-year period. This approach would mean minimal disruption for customers during the conversion.

Appliances Conversion (Section 5)

Hydrogen appliances and equipment for domestic, commercial and industrial sectors can be developed. There are already a few models on the market, although sales are extremely low, due to an absence of piped hydrogen. Just with the knowledge of this study, several manufacturers are showing real enthusiasm for their development. A firm long-term plan and significant stimulus would be needed to provide the motivation to develop and produce the wide range of equipment required. This could potentially be in the form of a national heat policy.

Hydrogen Transmission System (Section 6)

High pressure hydrogen transmission pipelines are operating around the world today. Similar pipelines have been proposed for carrying hydrogen from the SMR site to the conversion area and hydrogen storage sites. In addition a connection between the natural gas transmission system and the SMR has been proposed along with a pipeline from the SMR to CCS. Costs for these have been estimated at £230 million with ongoing OPEX costs of £0.5 million per annum.

Carbon Capture and Storage (Section 7)

The H21 Leeds City Gate project would give the following savings in CO_2 emissions:

	gm/kWh NG	gm/kWh H_2	% Reduction
UK Carbon budget basis (Scope 1)	184.0	27.0	85%
Including electricity for sequestration (Scope 1+2)	184.0	49.5	73%
Including embodied CO_2 from the production and importation of natural gas (Scope 1+2+3)	209.3	85.8	59%

The H21 Leeds City Gate project would sequester 1.5 million tonnes per annum CO_2.

Scope 1, net CO_2 savings for the area of conversion is 927,000 tonnes per year.

Carbon capture and storage technology is well established alongside SMR operations. An example of which can be seen in the Port Arthur SMR plants operated by Air Products in the USA.

Financial Model (Section 8)

Total costs associated with the project are summaries in the table below.

Cost Summary (£m)	Cost incurred (£m)	Ongoing costs each year (£m)
Network Capacity and Conversion Preparatory Work (Section 2.2)	10	
Hydrogen Infrastructure/Conversion Costs		
Steam Methane Reformer (SMR) Costs (Section 2.1)	395	
Intraday Salt Caverns (Section 2.1)	77	
Inter-Seasonal Salt Caverns (Section 2.1)	289	
Appliance Conversion (Domestic, Commercial and Industrial users within area of conversion) (Section 2.3)	1,053	
Hydrogen Transmission System (HTS) (Section 2.4)	230	
Ongoing OPEX Costs		
Carbon Capture and Storage		60
SMR/Salt Cavern/HTS Management		31
SMR Efficiency loss (30%)		48
Total	**2,054**	**139**

If the H21 Leeds City Gate project was funded using the current UK regulatory business plan it would have negligable impact on customers' total gas bills.

Next Steps, Programme of Works and H21 Roadmap (Section 9 and 10)

The earliest practical date for the initial hydrogen conversion of a UK city is 2025. In order to achieve this, several preparatory actions need to have taken place these are:

1. **2017 to 2022 –** Provision of finance to deliver the 16 work packages identified in this report with an estimated value of between £60m and £80m (See Section 10).
2. **2016/17 –** Establishment of the H21 Programme Team to co-ordinate and deliver the 16 identified work packages.
3. **2018 –** Provision of funding to begin the FEED/detailed design of the hydrogen production, storage and pipeline systems.
4. **2018 –** Clear direction by OFGEM that gas distribution networks need to allow provision within their GD2 business plans (2021–2029) to facilitate the conversion of the first cities.
5. **2021/22 –** A policy decision committing to the strategic, incremental material conversion of the UK gas grid over an agreed timescale.

The H21 Vision (Section 11)

The H21 Leeds City Gate Project has focused on the provision of heat through a 100% hydrogen gas network conversion for Leeds. Additionally by utilising gas industry expertise, some thought leadership has been provided around the impact of an incremental rollout of such a system across UK cities and/or regions. This has also considered the potential impact of establishing the first commercial hydrogen economy in the world.

Two rollout options have been presented and, alongside efficiency savings, both options could be developed with minimal impact on customers' overall bills.

General Considerations

1. The H21 Leeds City Gate Project has shown that the conversion of the UK gas distribution network to hydrogen would enable a dramatic reduction in UK emissions with circa 73% reduction from heat but also from transport and power generation.
2. Converting the UK gas network avoids the need to persuade householders to raise the funds and give up the space to install other complex low carbon technology. The absence of hassle for the customer is considered to be very important in the likely success of any decarbonisation strategy.
3. Leeds with circa 1% of the UK's population is a sensible starting point because of its size and geographical location, near to both Teesside (with its existing hydrogen infrastructure) and the salt beds north of Hull
4. The use of hydrogen storage addresses inter-seasonal storage, one of the known problems of trying to use only electricity as the energy vector for heat, This inherently smooths out:
   - The UK's large variation in inter-seasonal energy demand as hydrogen is produced and stored 'downstream' at a relatively constant rate throughout the year.
   - The production of CO_2 thereby simplifying sequestration
   - The wholesale natural gas purchases as the demand is relatively constant over the year for hydrogen production and storage and therefore this reduces the volume of natural gas required at periods of high demand (and therefore cost).
5. Low cost pipeline quality hydrogen (99.9%) can be purified to the very high quality gas required by fuel cells. Therefore a UK gas grid conversion to hydrogen could provide feedstock for automotive use, and via fuel cell combined heat and power open up the opportunity for an alternative to centralised power generation.
6. All of the individual steps in the hydrogen supply train (except for some appliances) are proven and widely available by competitive tender.
7. The project could stimulate the Northern Powerhouse bringing economic benefits to both the North and the UK economy as a whole.

The H21 Leeds City Gate project provides evidence that converting the UK gas network to hydrogen is technically possible and economically viable. A UK hydrogen conversion strategy could make a significant contribution towards meeting the challenge of the Climate Change Act as well as establishing the world's first hydrogen economy. It could also create a significant impact on UK GVA and establish a real anchor project around the Northern Powerhouse concept.

The Results

The results of the H21 project are detailed in the full report. it provides a clear description of how the work was undertake, what assumptions were made, what data was used and the conclusions.

For ease, the results were split into the following sub-categories:

Section 2: Demand vs. Supply

Section 3: Gas Networks Capacity

Section 4: Gas Network Conversion

Section 5: Appliance Conversion

Section 6: The Hydrogen Transmission System

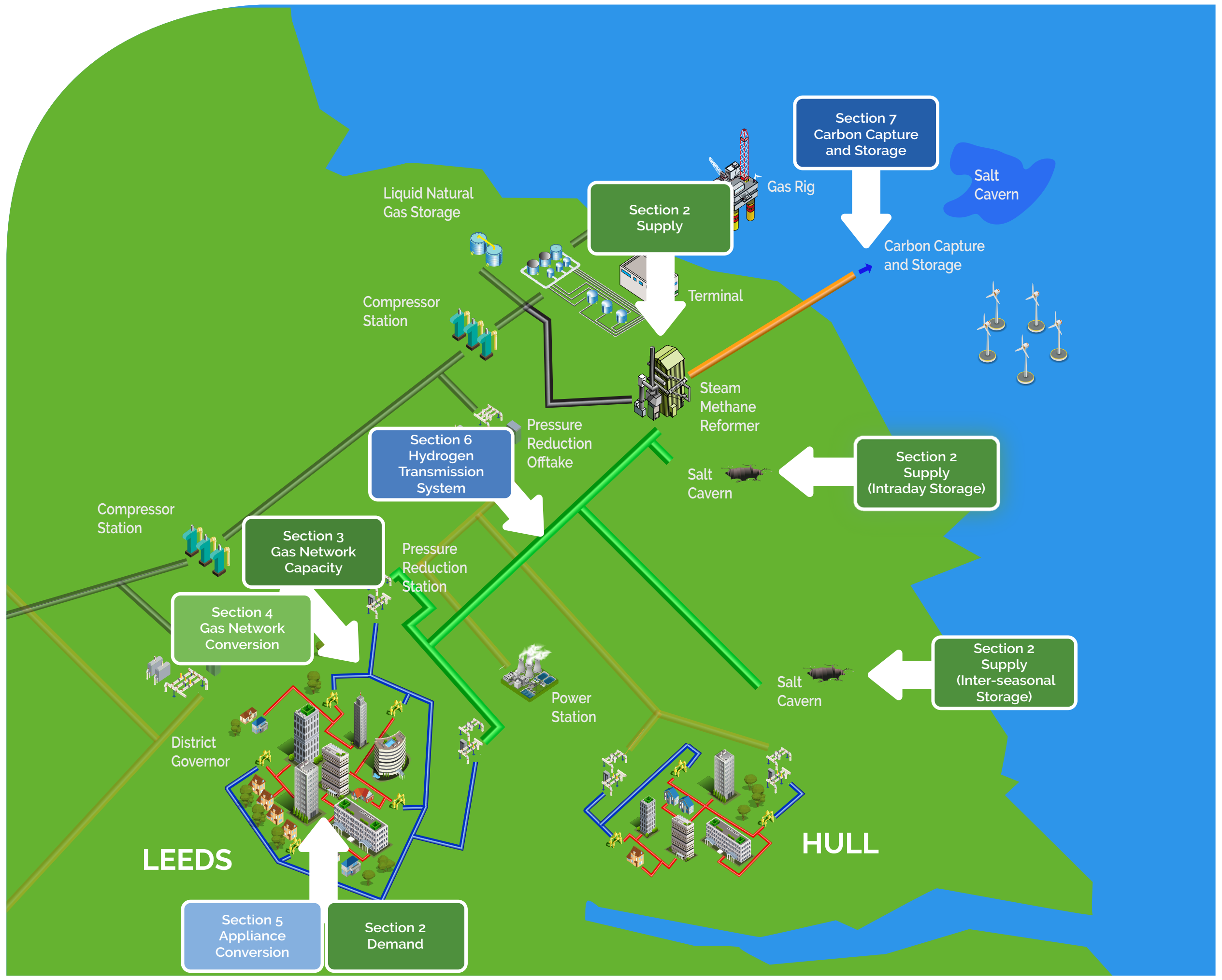
Section 7: Carbon Capture and Storage

Section 8: Financial Model

Section 9: The Next Steps - Programme of Works

These are illustrated on the next page.

H21 Leeds City Gate System Schematic



Notes

Northern Gas Networks