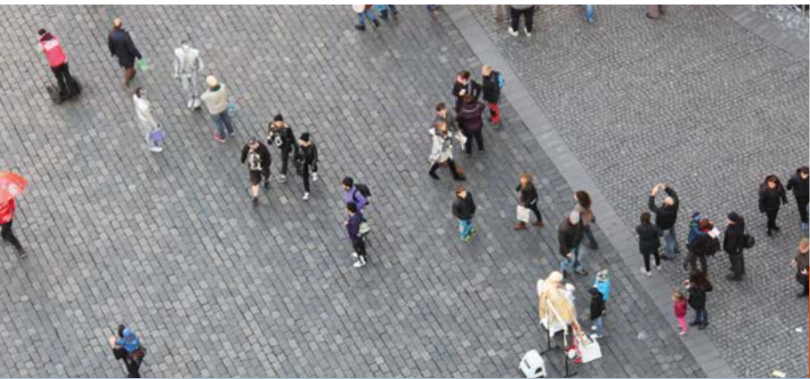
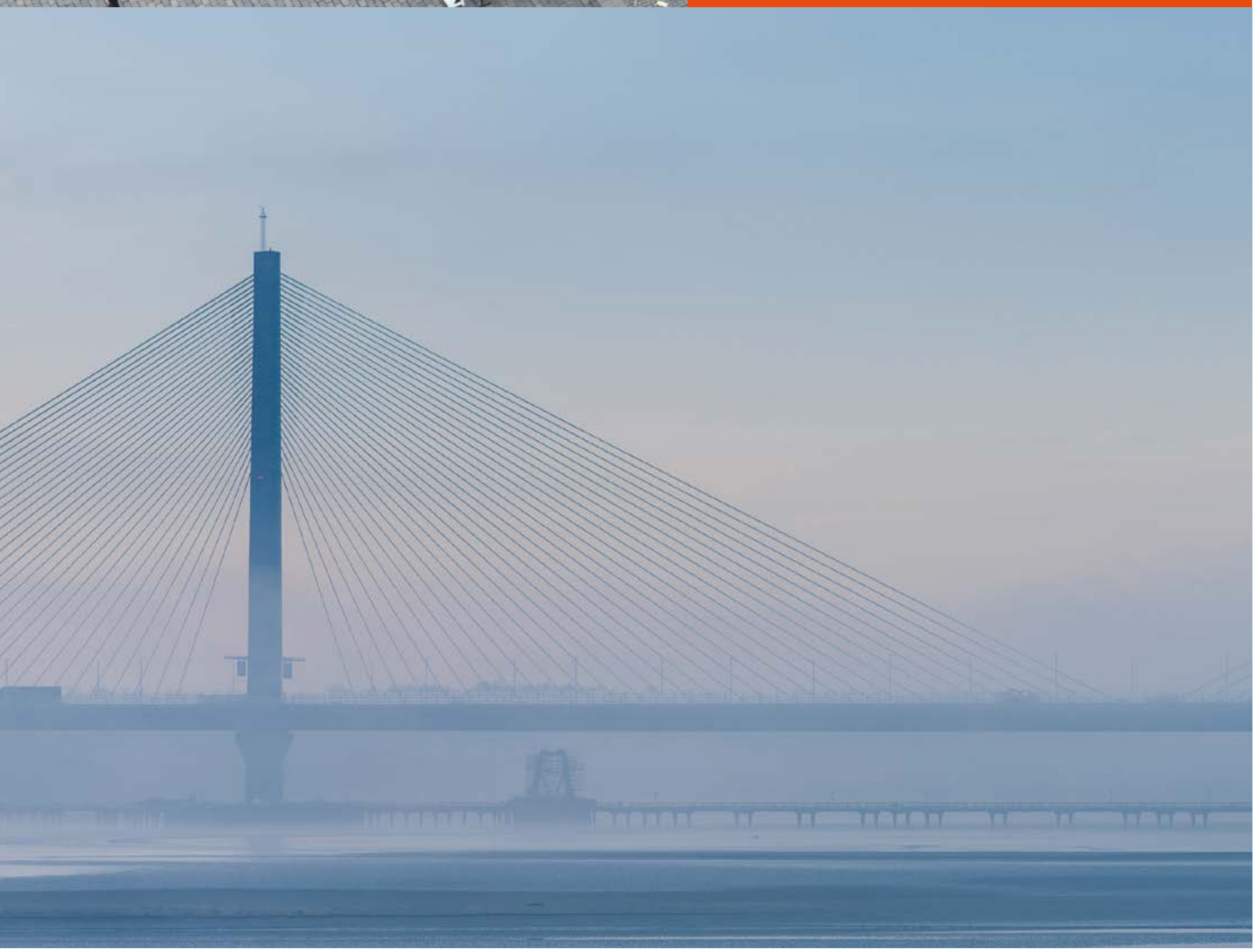
Cadent
Your Gas Network

HyNet North West

From Vision to Reality





Chris Train
HyNet foreword

Our HyNet North West project demonstrates a significant step in meeting our ambition to deliver clean, low carbon energy for our customers. This report sets out the latest position on this exciting, low cost hydrogen energy and carbon capture usage & storage programme.

Throughout the UK gas networks' 200 year rich history, it has demonstrated the need to continually adapt and embrace change to keep the gas flowing safely and reliably to customers. Today, this world class infrastructure delivers gas to around 85% of businesses and homes; and is an essential fuel to keep UK industry thriving. However, as we respond to the pressing need to accelerate decarbonisation to meet the UK's 2050 carbon targets, we must find new ways to deliver the best value for customers.

Practical and affordable solutions are needed. Innovative ideas must be turned into reality, particularly in the challenging areas of heat, transport and energy intensive industry.

Cadent has several pioneering projects exploring the future role of gas; including world leading technology for bio-synthetic natural gas; and future transport options. And, as hydrogen emerges as a viable, flexible future option for widespread decarbonisation and economic growth, Cadent is already leading HyDeploy, the first trial of hydrogen blended with natural gas for customers.

HyNet North West builds on this; setting out a clear pathway for large scale decarbonisation and economic growth for our customers in the North West.

HyNet tackles head-on the big issues of heat and industrial gas use, and provides a future route of hydrogen for transport. Delivering HyNet can reduce carbon emissions into our atmosphere by over a million tonnes per annum by the mid-2020s, at low cost and with minimal disruption by utilising existing gas infrastructure. More widely, it provides a replicable model of an integrated decarbonisation programme that could be rolled out for customers across the UK.

Crucially, HyNet also proposes a cost effective and practical way to deliver the UK's first Carbon Capture, Usage and Storage (CCUS) infrastructure by the mid-2020s. Its proposal to re-use the Liverpool Bay oil and gas fields infrastructure is an unparalleled economic, practical and timely option for CCUS demonstration which meets the ambition set out in the Government's Clean Growth Strategy (2017) to accelerate CCUS deployment.

At Cadent, we proudly believe that CCUS and hydrogen are vital in providing decarbonisation pathways that are at the lowest cost and of least disruption to our customers. HyNet North West delivers this.

The North West represents a unique opportunity to make HyNet a reality. The region's strong industrial heritage has long been committed to bold innovation and it is now poised to lead clean economic growth for the UK. HyNet can help to secure regional jobs and boost inward investment; as well as build the existing skills base into a sought after centre of expertise for hydrogen and CCUS technologies.

At Cadent, we are passionate about HyNet, but we cannot deliver it alone. Our customers in the North West, across regional government, industry and in homes and businesses will be crucial to its success. We are committed to continuing our work with a wide range of regional and national stakeholders who have the knowledge and drive to help bring the benefits of HyNet to life.

Chris Train
Cadent CEO

Executive Summary

HyNet North West (NW) is an innovative, integrated low carbon hydrogen production, distribution and carbon capture, utilisation and storage (CCUS) project. It provides hydrogen distribution and CCUS infrastructure across Liverpool, Manchester and parts of Cheshire in support of the Government's Clean Growth Strategy (CGS) and achievement of the UK's emissions reduction targets.

As shown in Figure ES1, hydrogen will be produced from natural gas and sent via a new pipeline to a range of industrial sites, for injection as a blend into the existing natural gas network and for use as a transport fuel. Resulting carbon dioxide (CO_2) will be captured and, together with CO_2 from local industry, which is already available, sent by pipeline for storage offshore in the nearby Liverpool Bay gas fields. Key data for the Project are presented in Table ES1.

Figure ES1: Overview of the HyNet Project

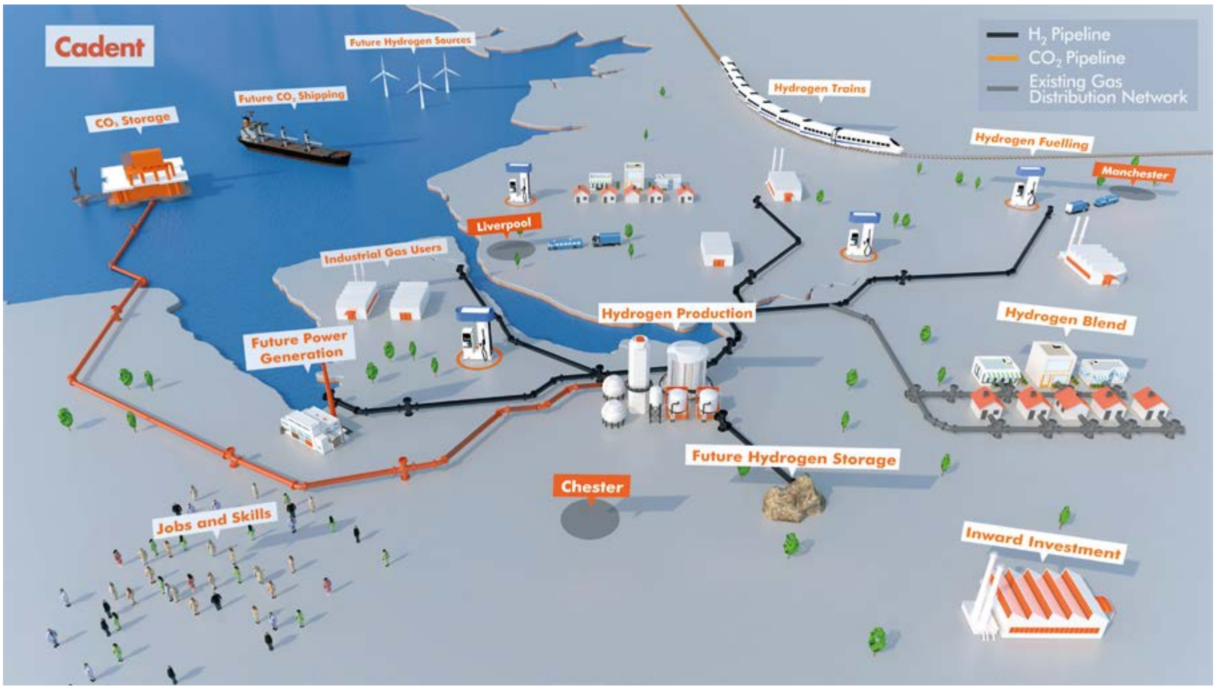


Table ES1: Key Data for HyNet Project

Parameter	Key Data
Peak displacement of natural gas use by industry	510 MW
Likely number of industry sites converted to hydrogen	10
Peak displacement of natural gas in the distribution network	380 MW
Number of homes and businesses receiving a hydrogen blend	>2 Million
Total CO_2 saved per annum	1.1 Million tonnes
Total cost of Project infrastructure	£920 Million

Section 2.0 of this report demonstrates that HyNet NW is a practical project that has been designed to be deliverable:

- Only proven technologies are used along the hydrogen chain;
- There is no disruption caused to gas customers, including industry;
- The Project risk profile is maintained within Business-as-Usual limits; and
- It is cost effective and represents a 'no regrets' policy option.

Section 3.0 highlights a range of benefits resulting from HyNet's specific design:

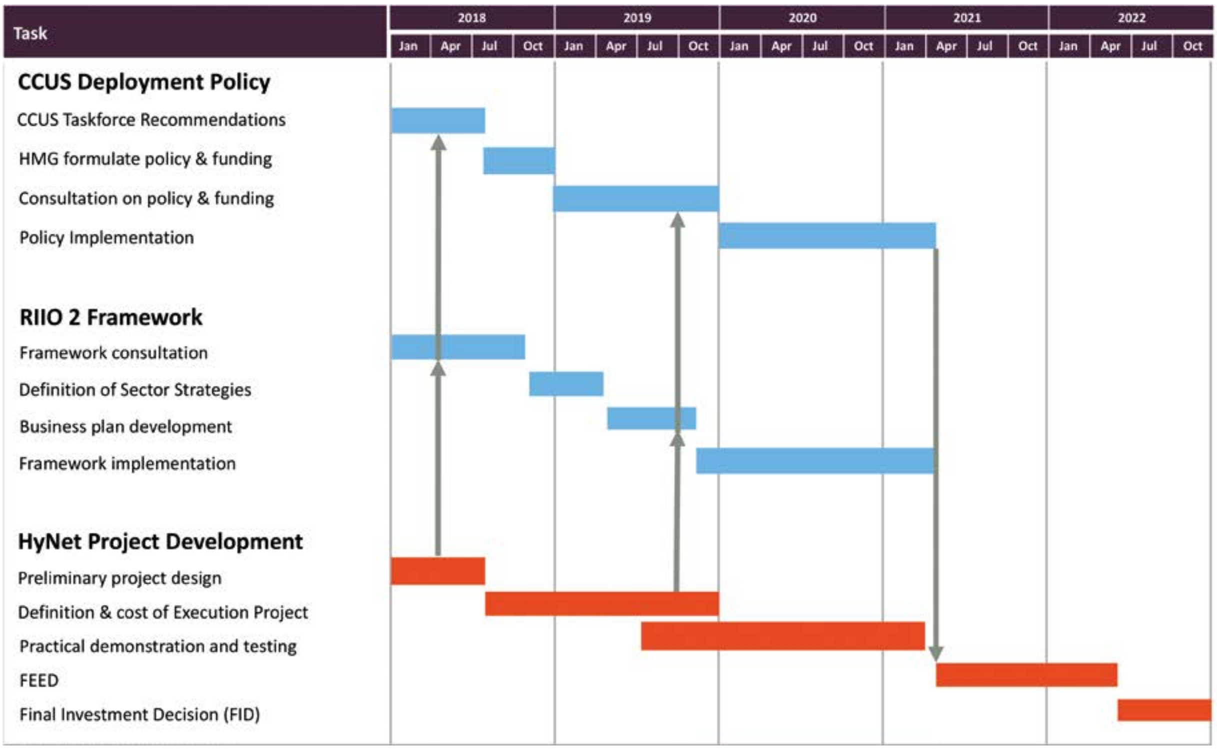
- Phase 1 can be deployed faster and at a lower cost of abatement than alternative low carbon heating solutions;
- The Project facilitates wide decarbonisation of most industry sectors, as a high proportion of emissions arise from combustion of gas and other fossil fuels for heat;
- The Project makes sensible use of existing infrastructure, both to reduce costs, and to facilitate long-term repurposing of the gas network;
- The Project is expandable and replicable across the Cadent region and the UK, and is a foundation from which to build the use of low carbon hydrogen to be a major contributor to the achievement of future carbon reduction targets;
- Gross Value Added (GVA) to the North West is of the order of £17 Billion to 2050, with average additional employment estimated at 5,979 jobs; and
- Further benefits to the UK (as a result of deployment in the North West) are £31 Billion of GVA and average additional employment of 11,259 jobs.

Section 4.0 of the report shows that the Project supports Government policy via:

- Timely and sufficiently rapid deployment to enable meeting Government's aspiration of having the option to deploy CCUS at scale in the 2030s;
- The first step towards creating low carbon gas as a key energy vector alongside electricity which enables cost effective achievement of 2050 emissions reduction in a flexible and cost effective way;
- Delivery of significant inward investment and opportunities to export products and services in line with the Government's Industrial Strategy; and
- Achieving such investment and growth, whilst also delivering material CO_2 abatement, consistent with the Government's CGS.

Section 5.0 provides further information in relation to Figure ES2, which shows how private investment can be leveraged to reach a Final Investment Decision (FID) by end 2022.

Figure ES2: Decision-making Framework Required for FID by 2022



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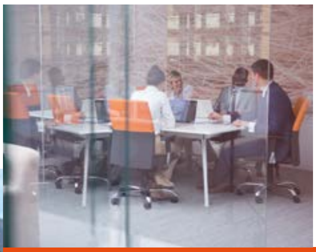
Acronyms

Acronym	Full Name
ATR	Auto-thermal Reformer
BEIS	Department for Business, Energy & Industrial Strategy
BioSNG	Bio-Substitute natural gas
Capex	Capital Expenditure
CCC	Committee on Climate Change
CCGT	Combined Cycle Gas Turbine
CCA	Climate Change Agreement
CCUS	Carbon Capture, Utilisation and Storage
CfD	Contract for Difference
CGS	Clean Growth Strategy
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
CoA	Cost of (CO_2) Abatement
EU ETS	European Union Emissions Trading Scheme
FID	Final Investment Decision
FiT	Feed-in Tariff
FOAK	First-of-a-kind
GDNO	Gas Distribution Network Operator
GVA	Gross Value Added
GWh	Gigawatt-hours
H_2	Hydrogen
HPCC	Hydrogen Production & Carbon Capture (plant)
ktpa	Thousand tonnes per annum
LCoH	Levelised Cost of Hydrogen

Acronym	Full Name
LEP	Local Enterprise Partnership
LTS	Local Transmission System
Mt	Million Tonnes
$MtCO_2pa$	Million Tonnes of Carbon Dioxide per annum
MWh	Megawatt hour(s)
MWth	Megawatt hour(s) thermal
NW	North West
OEM	Original Equipment Manufacturer
Ofgem	Office for Gas and Electricity Markets
Opex	Operational Expenditure
RAB	Regulated Asset Base
RHI	Renewable Heat Incentive
RIIO	Revenue = Innovation + Investment + Outputs
RO	Renewables Obligation
SMR	Steam Methane Reformer
tpa	Tonnes per annum
TWh	Terawatt hour(s)
TWhpa	Terawatt hour(s) per annum
vol.	By volume



1.0 Introduction

HyNet North West (NW) is an innovative, integrated low carbon hydrogen production, distribution and carbon capture, utilisation and storage (CCUS) project. It provides hydrogen distribution and CCUS infrastructure across Liverpool, Manchester and parts of Cheshire in support of the Government's Clean Growth Strategy (CGS) and achievement of the UK's emissions reduction targets.

Cadent is developing the project together with Progressive Energy. Cadent owns and operates the gas distribution network in the area, whilst Progressive Energy is an experienced clean energy project development company. ENI is the owner and operator of the Liverpool Bay oil and gas fields in which CO_2 will be stored, whilst other major local asset owners are also involved in project development.

The purpose of this report is to provide an update on the work that has taken place since the publication of Cadent's hydrogen 'Clusters' report in August 2017.[1] To avoid duplication, this previous work is referenced throughout this report.

2.0 A Real, Deliverable Project

The 'hydrogen economy' has been promised for many years – decades even; with the promise of low cost, high efficiency fuel cells and other game-changing developments. HyNet NW is different. It represents a deliverable project that is grounded in reality, reuses existing infrastructure and builds on cost effective technology that is available today. The focus is upon technologies that are cost effective and deliverable now. These will be deployed in a limited number of industrial plants and used to inject hydrogen as a blend into the gas distribution network at a level which does not require changes to consumer appliances and hence is readily achievable.

2.1 Project Philosophy

Focussed on the principle of deliverability, there are a number of features which form the HyNet project philosophy, as summarised in Table 2.1.

Table 2.1: Summary of HyNet Project Philosophy

Attribute	Description
To be the lowest cost approach to heat decarbonisation compared with alternatives	For many industrial plant, particularly those using direct-firing, there are no viable low carbon alternatives. As described in Section 2.4, in respect of Cost of Abatement (CoA), HyNet NW represents sound value for money compared with alternatives and is more likely to be affordable to Government.
To provide for a meaningful, low cost pathway to meeting the UK's 2050 decarbonisation targets	Meeting the 2050 targets will require deep decarbonisation of the heating, electricity and transport sectors, as well as electricity. This is a massive task, which must be achieved at the lowest cost to be affordable. HyNet has therefore been designed to be the lowest possible cost lead project of this nature. Section 3.2 describes how a large proportion of future cross-sector decarbonisation can be achieved to meet the UK's 2050 targets.
To provide a material level of CO_2 abatement that is deliverable	Significant abatement can be delivered by focussing on a limited number (~10) of major industrial gas users. Many of their emissions derive from combustion to produce process heat from boilers, which are relatively easily converted to high proportions of hydrogen. The blend of hydrogen injected into the gas network is at a level which involves no change to appliances and no disruption to consumers. 100% hydrogen conversion to hydrogen would require replacement of all domestic boilers and is therefore a longer term proposition.
To match the Project's risk profile with Business as Usual (BAU) risk profiles	To justify investment and reduce the cost of capital, the project has been designed to minimise risks. The hydrogen production plant is based on proven technology, and has multiple units to maximise supply reliability. Having multiple hydrogen customers reduces counterparty demand risk. Industrial users retain natural gas supply, which enables use of varying hydrogen and natural gas mixtures, and provides supply resilience. Multiple CO_2 stores are available to minimise storage risk, whilst commercial segregation of hydrogen production and use from CCUS will minimise cross chain risk.
To provide a foundation that can be extended outwards or replicated elsewhere in the UK	The project is designed for expansion and to be the first major step in decarbonising heat and creating CCUS and hydrogen infrastructure for subsequent heat, transport, power and industrial decarbonisation both locally, by project extension and by replication elsewhere. These are described in detail in Section 3.1.
'Oversizing' infrastructure is balanced with the need for low costs	Whilst the design of both the CO_2 and 'trunk' hydrogen pipelines for HyNet provide for additional customers to join in the future, these have not been oversized to the extent that the Project becomes unaffordable.
To be a significant but 'no regrets' step forward, which can be supported by policy-makers	Deployment of the HyNet Project would not lock the UK in to any kind of specific energy future. Even if no further hydrogen or CCUS development were to take place beyond the deployment of HyNet NW, the Project could standalone and deliver significant CO_2 abatement at a competitive cost compared to alternatives over the project lifetime. With planned operation in 2025, it would also provide the learning and evidence base needed to inform heat decarbonisation and CCUS deployment strategy in the 2030s.
To create a new industry, which builds on the existing local skills base, and drives global export of products and services	The North West has a rich history in gas extraction, processing and productive use. Section 3.3 describes the skilled local supply chain, which is ready to service the HyNet Project and to sell the resulting expertise and intellectual property (IP) on a global basis. This will also result in significant job creation across the North West and wider UK.

2.2 Reference Project Design

HyNet NW is built around a Hydrogen Production and Carbon Capture (HPCC) plant which produces hydrogen from natural gas. The location for the plant has been selected to minimise both the cost of connection to a CO_2 transport network, which utilises repurposed existing gas pipelines, and the distance from the large industrial gas users to be converted to hydrogen.

Autothermal reforming (ATR) has been chosen as the production technology. ATR offers increased gas process efficiency compared to steam methane reforming (SMR) and the production of hydrogen at pressure results in reduced compression costs. Two units are planned with a total capacity of 890 MWth.

The hydrogen produced is transported via a new pipeline to participating industry sites and injected into the existing natural gas Local Transmission System (LTS) to create a blend. The pipeline can be routed, in part, along existing easements and sized to provide sufficient 'line-pack' to enable management of daily demand fluctuations and provide the potential for growth. The availability of the hydrogen pipeline distribution system also facilitates the creation of hydrogen refuelling stations to support the use of hydrogen as a fuel in the road and rail transport sectors.

The CO_2 captured at the HPCC plant is sent, together with existing CO_2 already separated at a nearby industrial site, for underground storage at the Hamilton and Lennox gas fields in Liverpool Bay. It is transported via a section of new pipeline which connects to existing natural gas pipelines which will be repurposed for CO_2.

A schematic representation of the Project, including some potential extensions beyond Phase 1 (as detailed further in Section 3.1), is shown in Figure 2.1, whilst key technical data in respect of the Phase 1 Reference Project are provided in Figure 2.2.

Figure 2.1: Indicative Representation of the HyNet Project

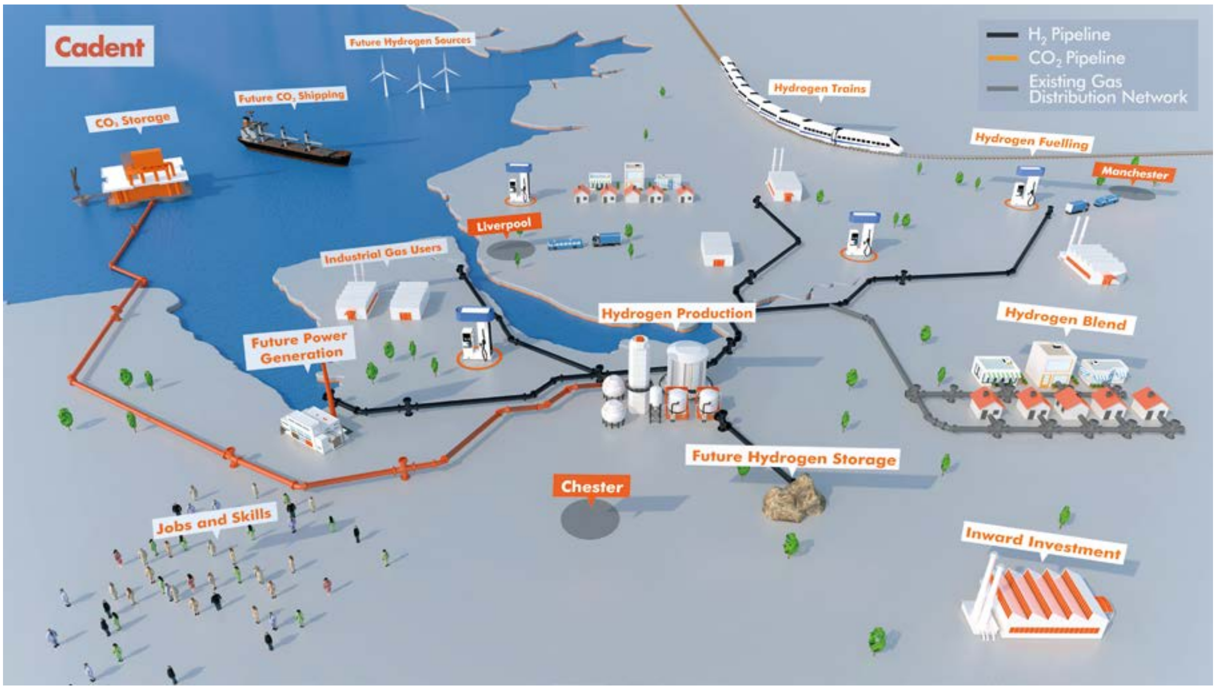
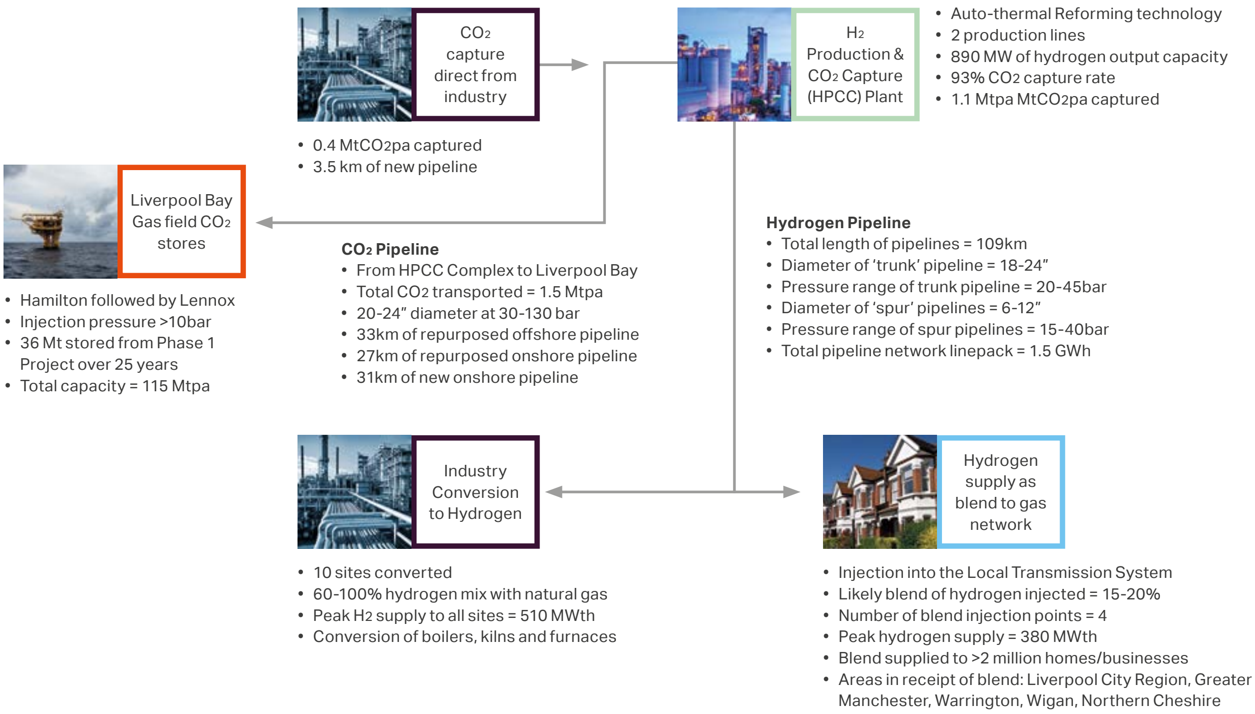


Figure 2.2: Key Data for HyNet NW Phase 1 Reference Project



2.3 Project Economics

Initial conceptual-level cost information was published in the previous Clusters report relating to the HyNet project. Since then, further optioneering and engineering design has been undertaken to provide the next level of detail in terms of project definition and cost data. This is presented in Table 2.2 and suggests that Capex for the Reference Project would be of the order of £920 Million.

The increase associated with this estimate compared with that presented in the Clusters report is the result of the Reference Project being larger than the conceptual design produced previously and firmer definition and costing on some items. The most significant of these are:

1. **Hydrogen production costs**
   The previous estimate was based on secondary data published in relation to SMRs in another UK-led major hydrogen-related study. Consultation with OEMs and EPC contractors has since shown that this estimate was optimistic. At the same time, the adoption of ATR technology for the Project reduces Capex compared with SMR as well as delivering higher efficiency;

2. **Hydrogen pipeline costs**
   The previous estimate assumed around 90km of pipeline. In the interim, it has been determined that 109 km of pipeline is required to enable injection into the gas distribution network at locations which provide coverage of the complete Liverpool and Manchester areas.

The data in Table 2.2 shows that the cost of industrial conversion is relatively small compared with those relating to hydrogen production and distribution.

Table 2.2: HyNet Capex Data

Project Element[1]	Related Information	Average Unit Cost (£M)	Total Cost (£M)
Hydrogen Production and CO_2 Capture	HPCC plant comprises two ATRs, producing around 890 MW of hydrogen at pressure[2]	£256/unit	£513
Hydrogen Transport	Transport of 890 MW of hydrogen in new 109km onshore hydrogen pipeline from HPCC plant to industrial cluster and blend injection points	£1.65/km	£178
Hydrogen Compression and Injection to LTS	No compression required at HPCC plant, but additional equipment needed to inject hydrogen into the four LTS injection sites	£5/site	£20
Conversion of Industry to Hydrogen	Modifications to boilers, kilns and furnaces at 10 large industrial sites	£7.8/site	£78
CO_2 Transport	New 31km onshore pipeline from ATR plant to existing pipeline at Connah's Quay[3]	£2.03/km	£63
CO_2 Facilities	Modifications to existing Hamilton platform	n/a	£27
CO_2 Storage	Includes design, procurement, construction and commissioning of wells, licensing and permitting	n/a	£31
		TOTAL	£920

Notes:

1. The battery limit for CCUS costs is from the inlet to the CO_2 compressor at the HPCC plant
2. Includes costs of CO_2 compression
3. Also includes costs for modifications to existing gas pipelines which are repurposed for CO_2

The key high-level Opex items included in the financial model for this study are presented in Table 2.3. This analysis suggests that Opex for the project would be of the order of £85 M/annum.

Table 2.3: HyNet Opex Data

Project Element	Related Assumption(s)	Cost (£M/annum)
ATR (and hydrogen injection equipment) O&M	Based on 3% of Capex	16
Electricity for Hydrogen Compression	From <19 bar to 33 bar for injection into the LTS	3
Additional natural gas requirement	£15.35/MWh (45p/therm) price of natural gas and 93% efficiency of ATR[1]	24
Electricity for CO_2 Compression	To 10 bar at project initiation rising up to 60 bar at end of 15 year project period	26[2]
Onshore Hydrogen and CO_2 pipelines O&M	Based on 3% of Capex	6
Offshore CO_2 Transportation O&M	Based on ETI (2016)	1
CO_2 Facilities O&M	Based on ETI (2016)	8
Measurement, Monitoring & Verification (MMV) of CO_2	Based on ETI (2016)	0.4
Financial Security against CO_2 leakage	Based on ETI (2016)	0.6
Injection Well 'Workover'	Based on ETI (2016)	0[3]
Offshore Abandonment	Excluded	0
	TOTAL	**85[4]**

Notes:

1. Based on data contained within BEIS (2017) Updated Energy and Emissions Projections, December 2017
2. Year 1 cost, rising to £27.5 M/annum in year 15
3. A cost of £11.6 M is modelled for Year 10 only
4. Excludes savings associated with avoidance of need to purchase EU Allowances (under the EU Emissions Trading Scheme) by industry

Using the Capex and Opex data presented in Table 2.2 and in Table 2.3, a levelised cost of hydrogen (LCoH) has been calculated. The model uses different required internal rates of return (IRRs) for each different element of the hydrogen and CCUS infrastructure, depending upon the associated level of risk and therefore likely form of finance. This approach results in a LCoH of around £38/MWh, which represents a £23/MWh uplift on the current price of natural gas of around £15/MWh.

As described in Section 5.1.2, the proposal, which is in line with the funding of other emissions reduction initiatives is that individual consumers or areas do not bear increased energy costs above the current price paid for natural gas. Rather that these costs are shared across all customers.

2.4 Lowest Cost Heat Decarbonisation

2.4.1 Cost of Abatement

Government is seeking to achieve the emissions reduction targets enshrined in law by the Climate Change Act at the lowest possible cost. Alternatives exist across different sectors of the economy as well as within each sector and a key metric in comparing the Project with alternatives is the cost of (CO_2) abatement (CoA).

It is therefore necessary to first calculate the total annual abatement from the project. As presented in Table 2.4, the tonnage of CO_2 abated by the Project is largely a function the efficiency of the HPCC (or ATR) plant, both in terms of gas production/use and with regard to the capture of CO_2 and the associated electricity demand. It is also a function of the counterfactual emissions from burning natural gas (in the absence of the Project). The assumptions shown in Table 2.4 result in total abatement for the Project of 1.14 $MtCO_2$/annum.

Table 2.4: Annual Abatement from the L-M Hydrogen Cluster Project

Parameter	$MtCO_2$/annum
Total capture by ATR (@ 93% capture rate)	1.09
Total abated from other industry, which is already separating CO_2	0.40
Total emitted by ATR[1]	0.13
Process efficiency loss[2]	0.22
Total Annual Abatement[3]	1.14

Notes:

1. Includes 7% uncaptured emissions and those associated with electricity demand (largely CO_2 compression)
2. Relates to emissions associated with the difference between the amount of energy input (in natural gas) and the amount of energy output (in hydrogen)
3. Excludes net uplift in emissions associated with the greater upstream gas production

In its simplest form the CoA is the sum of the capital and operational costs (presented in Section 2.3) divided by the total lifetime CO_2 abated. However, this would ignore the cost of the counterfactual technology, in this case heat from unabated natural gas. Consequently, the approach taken here is to calculate the total lifetime support required by the Project (such that it is competitive with unabated natural gas) and to divide this by the total CO_2 abated over the Project lifetime. Based on this approach, the CoA associated with HyNet is £114/tCO_2.

As presented in detail in the previous Clusters report, this CoA remains highly favourable compared with many other forms of decarbonisation in the energy sector. In specific respect of heating (and transport), work undertaken by KPMG on behalf of the Energy Networks Association (ENA) suggests that to achieve the UK's 2050 carbon targets using electric heat pumps and electric boilers would cost households more than double that of an approach based on their 'evolution of gas' scenario, i.e. where hydrogen (and biomethane) are widely adopted.[2] In addition, further work on the comparative costs of new low carbon heating solutions will shortly be published by the National Infrastructure Commission (NIC), which will provide further evidence and comparison for policy makers.

Furthermore, from a technical perspective, conversion to hydrogen represents the only viable way to decarbonise much of energy intensive industry; particularly processes which involve direct-firing. Consequently, this analysis suggests that HyNet NW should form a key part of the Government's CGS.

2.4.2 Future Cost Reduction Profile

As described above, the aim has been to design and structure the initial Project to produce a CoA that is competitive compared to alternative decarbonisation options. It is relevant to note, however, that there is real potential for cost reduction over time in line with the experience of introducing other low carbon energy technologies, such as electricity generated by offshore wind.

Cost reduction might be achieved, for example, by:

- For future demand (across industry, power and transport), using available capacity in the CO_2 transport and storage system, which could result in savings of around half of the costs for these elements compared with Phase 1;
- Utilisation of lower cost oil residue or possibly feedstock to be converted to hydrogen (with CCUS), which could reduce hydrogen production costs by around 30%; and
- Utilisation of the full capacity of the hydrogen distribution network to be installed, which would also significantly reduce costs in relation to new demand.

In addition, the 'learning by doing' benefits which provide confirmation of processes and equipment behaviour and identify opportunities for cost saving and allow contingencies to be reduced will result in lower costs.

3.0 A Project with Wide-Ranging Benefits

3.1 Future Extensions of the Project

As presented in Figure 3.1, future major project 'extensions' or phases of deployment of HyNet will be facilitated by both:

- Additional CO_2 storage capacity in the Liverpool Bay gas fields (which have total storage capacity in excess of 0.2 Billion tonnes), a nearby aquifer with a capacity of around 0.3 Billion tonnes and a further 1 Billion tonnes in the nearby Morecambe Bay gas fields; and
- The availability locally of underground hydrogen storage in salt caverns to help balance future fluctuations in demand which cannot be managed via approaches used for Phase 1 of the Project. Such storage is technically proven and can be developed in the nearby vast Cheshire salt basin, which is currently used extensively to store natural gas. Further salt formations suitable for storage also exist nearby offshore.

As described in the previous Clusters report, the Project has been designed to be extendable into many subsequent different phases and types of development. Within the North West itself, these include the conversion of further new and existing industrial sites, injection of a hydrogen blend into the wider gas network, roll-out of vehicle refuelling stations, and the development of flexible power generation, for example, hydrogen-fuelled combined cycle gas turbines (CCGTs) and fuel cells supplying local heat and power needs. A future deployment pathway which includes all these possibilities is reflected in the analysis for the future role of gas in Section 3.2 and in the modelling of Gross Value Added (GVA) in Section 3.3. An expansion opportunity which has not yet been quantified is the capture and storage of biogenic CO_2 (BECCS), for example from the production of BioSNG or Biohydrogen.

HyNet might also be expanded geographically in all of the above ways, yet still anchored to the North West via CO_2 injected at Liverpool Bay and beyond. This might be delivered by way of hydrogen pipelines to, for example, the West Midlands or West Yorkshire, or CO_2 delivery to Liverpool Bay for storage, for example by ship from an industrial 'cluster' in South Wales. The Committee on Climate Change (CCC) suggests that decarbonisation of Welsh industry via this route might be more cost effective than alternatives, and therefore models a scenario based on CO_2 transport by ship to an existing storage network.[3]

At the same time, geographical extension of the HyNet concept might be linked to other opportunities for the development of low cost CCUS infrastructure by replication of the Project. A significant proportion of industrial emissions in the Cadent area come from the Humberside industrial cluster and, as noted in the previous Clusters report, a number of storage sites are readily accessible (including Viking, one of the five 'preferred' storage sites identified by the Energy Technologies Institute as part of a major study in 2016).[4] Salt cavern storage is also available on Humberside and the Clusters study confirmed that it is a strong candidate location for a follow-on industrial hydrogen and CCUS cluster. Teesside and Grangemouth may also be candidate locations.

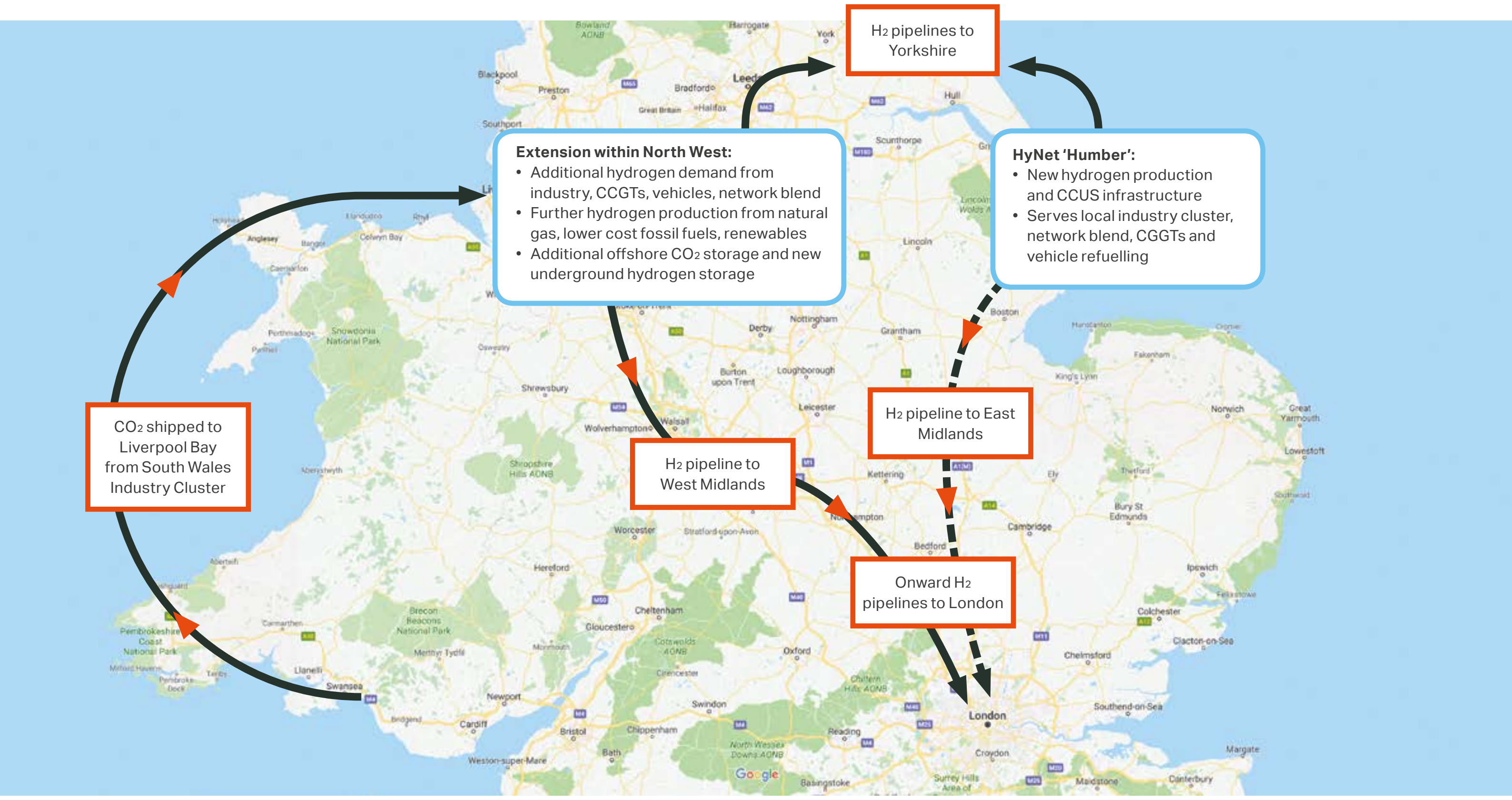
The above geographical extensions represent a longer-term vision to decarbonise the wider UK. This approach can be complementary to other initiatives, such as the H21 Project, and is consistent with plans for future decarbonisation of the North, which are being developed by the Northern Powerhouse.[5]

Production of hydrogen from natural gas is currently the most straight forward option for hydrogen production.[6] Other options for manufacture of bulk hydrogen exist commercially, notably gasification of coal and of heavy fuel oil and oil refinery residues. Such options provide increased energy security to the UK, avoidance reliance on a single fuel and increasing resilience to price shocks in the event of long term price shocks.

In addition the existence of hydrogen pipeline distribution network infrastructure created by the HyNet Project will promote and attract hydrogen generated from renewables, such as wind, solar, tidal and biomass. To this end, it could, in principle, help to support the development of new low carbon and renewable electricity generation infrastructure by reducing the cost of energy off-take, particularly where electricity grid constraints exist and providing an alternative route to market for power generation projects during periods of low electricity demand.

Consequently, there is real potential to reduce the overall cost of hydrogen used in the Project, which will reduce the LCoH, as presented in Section 2.3.

Figure 3.1: Facilitators and Opportunities for Project Extension



3.2 The Role of Gas in Achieving 2050 Carbon Targets

Cadent owns and services the gas distribution infrastructure which supplies gas to nearly half of all UK customers. This infrastructure serves key centres of population, including Liverpool, Manchester, Birmingham and London, and key industrial clusters in the North West and Humberside. Based on analysis of publicly available data, this region represents almost half of UK's CO_2 emissions.

In designing the HyNet NW Project, consideration has been given to the role of gas in cost-effective decarbonisation of the whole Cadent area, to enable meeting of the 2050 target (and the mandatory five year carbon budget targets), as required by the Climate Change Act (2008). A pathway to 2050 has therefore been modelled, which is based on the following deployment strategy:

1. Reduce the carbon intensity of the existing gas distribution network by:
    a. Blending in low carbon hydrogen at a level which does not require changes to consumers gas appliances; and
    b. The addition of biomethane and BioSNG.
2. Supply up to 100% hydrogen to large emissions sources, notably in industry and power, where technology is already available;
3. Focus on the areas of greatest need, for which low carbon gases, hydrogen in particular, are expected to provide a cost effective decarbonisation option. These include:
    a. Heat supply;
    b. Flexible power to balance intermittent renewable generation; and
    c. Certain transport applications e.g. HGVs, buses and trains, to displace carbon intensive petrol and diesel.

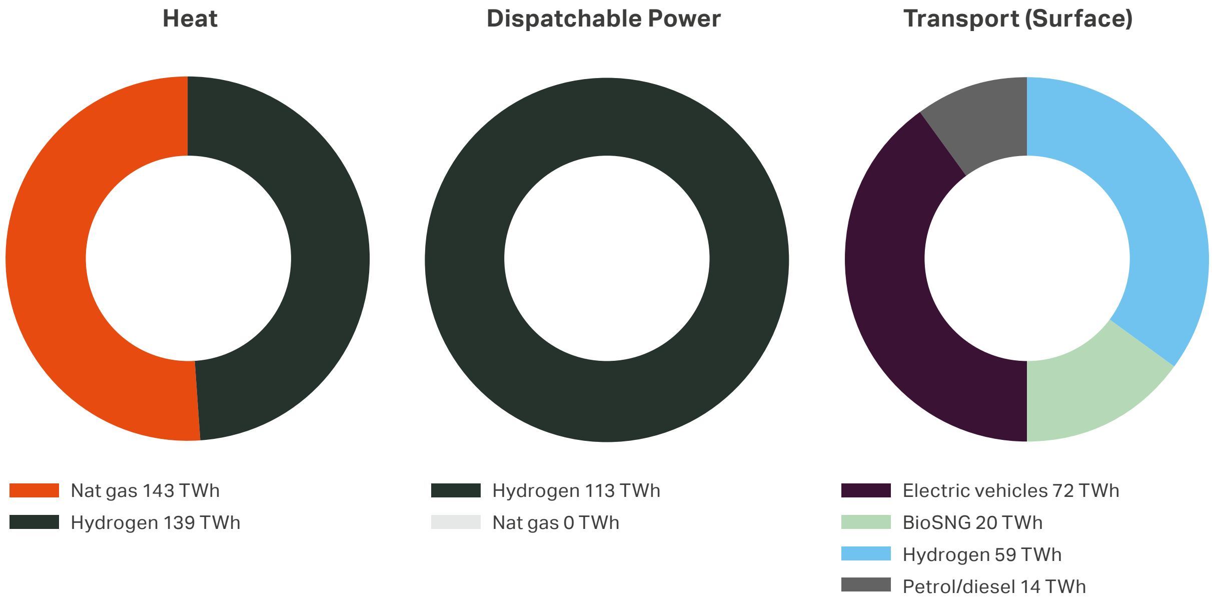
Taking the central scenario produced by the CCC as a starting point, Figure 3.2 indicates that supplying around 300 TWh of low carbon gas enables the 2050 target to be achieved.[7] The approach differs from the CCC central scenario in that it:

- Requires less nuclear. In effect it recognises that renewables plus flexible, mid merit, electricity generation from decarbonised hydrogen have the potential to produce lower cost electricity than nuclear;
- Recognises that hydrogen vehicles could well provide a transport solution, particularly for large vehicles and trains; and
- Focuses on using hydrogen to reduce emissions from combustion for heat in industry, together with the progressive adoption of hydrogen for heating in new industrial and large estates of commercial/domestic buildings.

As presented in Figure 3.2, around 300 TWh of low carbon gas could be used to supply around half of all heat demand (across all sectors), one third of all transport needs and all flexible power demand. The value of this approach is that it demonstrates the potential of low carbon hydrogen and BioSNG to make a major contribution to the achievement of the UK's emissions reduction obligations, avoiding reliance solely on low carbon electricity.

Pro-rated direct CO_2 emissions in the Cadent area in 2015 were 186 Mt and the modelled low carbon gas activities represent a combined saving of 104 $MtCO_2pa$ by 2050, as shown in Figure 3.2. This delivers a 2050 compliant scenario when combined with non-hydrogen related savings, such as underlying removal of coal from the power sector and a significant rise in the use of electric vehicles (EVs), and accounting for changes in non-CO_2 emissions, both as identified by the CCC.

Figure 3.2: Potential Low Carbon Gas use in 2050



CO_2 Savings in 2050 against a 2015 baseline

Heat	Dispatchable Power	Transport (Surface)
37.3 Mtpa	47.2 Mtpa	19.5 Mtpa

The actual mix across sectors and between low carbon gas and alternative solutions will depend on technology developments over the coming decades and their relative cost compared to alternatives. For example, some of the flexible power requirement could be met by CCGT with post combustion CO_2 capture (rather than CCGT fuelled by hydrogen), or by disruptive technologies such as the NetPower technology.[8] Deeper penetration of hydrogen to provide heat to the domestic consumers would be achieved by full conversion of cities as envisaged in the H21 programme.

A key benefit of the approach modelled here is the optionality provided by creating two low carbon energy vectors, low carbon electricity and low carbon gas, so that the lowest cost solutions can be deployed as technologies and circumstances change over the next 30 years.

The HyNet Project has been structured to be the first phase of a programme to achieve this vision. The first phase will provide 6 TWh per annum of low carbon hydrogen and is the platform from which wider growth can take place.

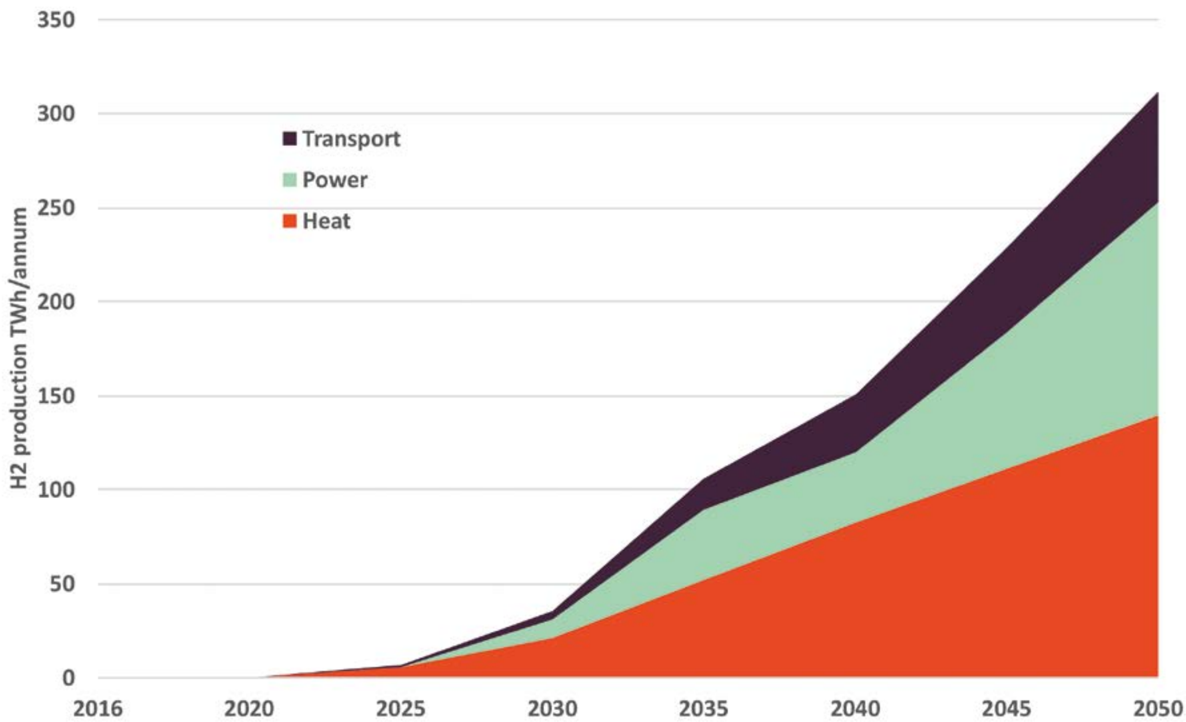
The pathway is illustrated in Figure 3.3 and includes the extensions of HyNet NW highlighted in Section 3.1. It can be summarised as follows:

- Before 2030, HyNet NW is expanded within the North West adding further industrial heat and transport fuel is provided along with new power applications;
- At the same time, it also expands geographically to incorporate other centres of population, industry and power generation sites, such that annual production of low carbon gas reaches around 30 TWh in 2030;
- The Project is replicated at Humberside, predicated on the large industrial cluster (based on publicly available data, the Humberside cluster of industrial and power plants might contribute 30-35% of industrial and power sector emissions in the Cadent area), such that annual low carbon gas production reaches over 100 TWh within the sixth Carbon Budget; and

- Further expansion proceeds incrementally, dictated by its cost effectiveness, with hydrogen infrastructure reaching further centres of population and industry to reach over 300 TWh of low carbon gas production in 2050.

The 2050 pathway modelled for GVA and job creation in Section 3.3 assumes a similar pathway, albeit the modelling of economic benefits is constrained to the North West only, rather than the full Cadent area as with this approach.

Figure 3.3: Build-up of Hydrogen Supplied to 2050



The CCUS infrastructure created as part of the HyNet NW and HyNet Humberside projects allows further direct industrial CO_2 capture projects alongside hydrogen conversion projects. It also enables the storage of $BioCO_2$, for example from the production of BioSNG and BioHydrogen, where capture of CO_2 is an inherent part of the process. The value of BECCS in meeting the UK's obligations formed part of the CCC's 2011 Bioenergy review and its importance is becoming increasingly widely recognised.[9] The additional carbon savings associated with this have not been taken into account in this assessment.

In summary, this approach enables the Cadent area to play its part in meeting both the 6th Carbon budget in the mid-2030s and the UK's 2050 obligations. It is effectively a variant of the CCC's central scenario, but using hydrogen combined with CO_2 storage to move the burden away from disruptive changes to domestic consumers heating systems.

This approach is not the only pathway, which includes a large contribution from low carbon gas, to meeting the 2050 obligations. However, the combination of blending into the gas network for domestic heat, decarbonisation of industry and the contributions from hydrogen use in transport and dispatchable power provides a customer-focused, 2050 solution.

3.3 Benefits to the Economy

Extensive interaction has taken place with many of the manufacturers that make up the 'cluster' of major industrial gas users, which may convert to hydrogen. This industrial cluster includes global companies and brands across many sectors; from chemicals, glass and oil refining to food, paper and automotive.

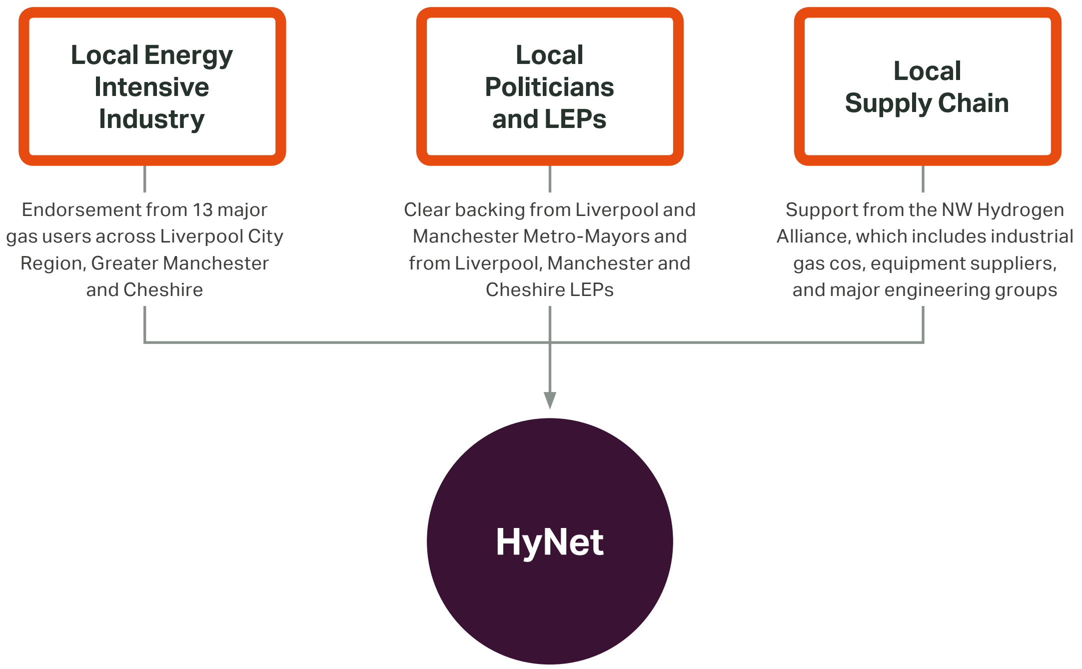
For these companies, low carbon hydrogen (like all other low carbon solutions), provided it is supplied at a price which is competitive with natural gas and related technical challenges can be overcome, is a potentially attractive substitute fuel for heat generation or for use in manufacturing processes. In addition, the availability of CCUS infrastructure, deployed as part of the Project, is of potential interest to wider process plant for which fuel substitution is not possible. This 'North West Industry Cluster' supports the development of a low carbon hydrogen production and distribution network in the North West, with 13 organisations pledging 'in principle' support with a commitment to engage with Cadent and Progressive to explore the potential to convert to hydrogen.[10]

In addition, there is a wider group of organisations, including suppliers of industrial gases, burner manufacturers, design engineers and landowners, which form part of a broad 'North West Hydrogen Alliance'. A large part of the supply chain required to design, construct and operate the Project is represented in this Alliance. As described below, the forecast participation of the local supply chain is reflected by the significant local economic benefits and job creation estimated to occur as a result of HyNet NW.

The stakeholder engagement process for HyNet has included the Local Enterprise Partnerships (for Liverpool, Manchester and Cheshire), the Metro-Mayors for Liverpool and Manchester, along with several local authorities. All of these see the benefits that the Project can bring to the area and support the Project.

The above suite of diverse, but consistent support is summarised in Figure 3.4.

Figure 3.4: Overview of Regional Support for HyNet NW



To provide an estimate of the economic benefits of HyNet NW, AMION Consulting was commissioned to undertake an independent study of the Gross Value Added (GVA) and employment that the project would bring to the North West and wider UK economies.[11]

The analysis includes Phase 1 of the Project, and its potential extension within the North West, to include further conversion of industry, the development of hydrogen fuelled CCGTs and further deployment of vehicle refuelling stations. All benefits modelled for the wider UK are the result of developments in the North West only and do not include the potential future benefits of potential extensions of HyNet outside the region.

The study considers the direct benefits from the Capex and Opex of the project and also includes the potential impacts of inward investment attracted as a result of the Project. In the study, the Capex and Opex associated with each part of the Project; for example, hydrogen production or CO_2 pipelines, is split into design, equipment and construction elements. For each of these, the proportion that will be spent in the North West and wider UK is estimated.

The impact modelling uses a 'multiplier' structure that takes into consideration not only direct and first-tier supplier spending/employment but subsequent supply-chain spend and the 'induced' spending of those in receipt of wages/salaries as part of this process. It also takes into consideration the impact of inward investment (in the form of new manufacturing plant), which will be driven by the opportunity for low carbon production in the North West.

As summarised in Table 3.1, the results of the modelling suggest that the combined impacts from spend on the initial Project (and extensions) and from inward investment will result in GVA of around £17 Billion for the North West and £31 Billion for the UK as a whole (including the North West) to 2050. Over the same period, some 191,000 'person years' of employment will be created in the North West and 360,000 in the UK as a whole.

The report does not, however, include any assessment of the impacts related to the take-up of large transport, utility or domestic fuel cell electric vehicles (FCEVs) nor does it consider the potential for the manufacture of FCEV engines/vehicles within the North West. Furthermore, it does not include any analysis of wider potential for import substitution of fuels (i.e. using hydrogen as an alternative to fossil fuels) or any potential 'export' benefits for the region from providing CCUS infrastructure for other regions. Consequently, the report from AMION Consulting states that the study presents a relatively conservative perspective on impact.

Table 3.1: Total Employment and GVA Impacts (up to 2050)

GVA (£m)	NW	UK (including NW)
Direct	14,044	25,956
Inward Investment	2,836	4,584
Total	**16,880**	**30,540**
Employment (Total Employment Years)	**NW**	**UK (including NW)**
Direct	144,287	289,377
Inward Investment	47,053	70,896
Total	**191,340**	**360,273**

Overall, during this period, average annual GVA generation for the North West is assessed as £528 million and £954 million for the UK as a whole, whilst average annual employment is forecast at 5,979 jobs for the North West and 11,259 for the UK.

Ultimately, therefore, this study suggests that HyNet would bring significant economic benefits to the North West and should therefore form an instrumental part of the Government's CGS.

4.0 A Project which Supports Government Policy

The Government currently faces a diverse suite of economic and environmental challenges, which demand swift and concerted action. The need to meet its legal obligations under the UK Climate Change Act (2008) and by 2050 to reduce emissions of carbon dioxide (CO_2) to 20% of 1990 levels will demand huge political will.[12] Similarly improving air quality, particularly in urban areas, to reduce impacts on human health, will require similar effort and innovation.[13] At the same time the UK faces the significant economic challenges presented by Brexit along with growing political instability and uncertainty in the wider global economy.

The Government has responded to these challenges with the UK's first formal Industrial Strategy of modern times.[14] This aims to form a new approach as to how government and business can work together and promotes the concept of a 'strategic' state, which intervenes decisively wherever it can make a real difference. Such intervention is critical in the context of supporting investment in major low carbon infrastructure like HyNet, which will simply not happen if 'left to the market'.

The Strategy also focuses on addressing low productivity in the UK. It highlights five foundations of productivity: ideas, people, infrastructure, business environment and places. The nature of HyNet suggests that 'strategic' intervention to help support the project would be consistent with these foundations, as is summarised as follows:

1. Ideas – HyNet is a FOAK in that it would be the world's first commercial scale hydrogen and CCUS project;
2. People – HyNet would build on existing skills and create new skilled jobs (see Section 3.3 for further details);
3. Infrastructure – HyNet would represent a major low carbon upgrade to the UK's energy infrastructure;
4. Business Environment – HyNet would create an environment in which industry can confidently invest in the long-term; and
5. Places – HyNet is also consistent with Greater Manchester and Liverpool City Region local energy and transport plans and presents an opportunity for significant economic growth across one of the less prosperous regions of the UK.

Accordingly, with an aim to put the UK at the forefront of industries of the future, the Industrial Strategy sets out a set of four 'Grand Challenges'. One of these is to follow a path of 'Clean Growth', which the Strategy suggests is one of the 'greatest industrial opportunities of our time'.

To help seize this opportunity, the CGS was published by the Department of Business, Energy and Industrial Strategy in October 2017.[15] Consistent with the Industrial Strategy, the CGS focuses on productivity, but emphasises that this must be achieved within a framework of clean growth. It highlights examples whereby the Government has previously made targeted, strategic interventions to support private sector innovation, which has resulted in new industries, cost reduction and greater productivity. One example cited is the offshore wind sector, which has been supported by Government, resulting in the costs of producing low carbon electricity halving in a short number of years, a new industry thriving, whilst also delivering significant reductions in CO_2 emissions.

The CGS emphasises the need to replicate the success of the offshore wind sector across other sectors of the economy. The CGS suggests that heat decarbonisation is the most difficult policy and technology challenge associated with clean growth. It states that it must be demonstrated how hydrogen would work in the existing gas network and how it can fire industrial processes without impacting upon operations. As described in Section 5.2, these are the very challenges that the HyNet NW Project seeks to address, building upon existing demonstration projects, such as HyDeploy, which is also led by Cadent.[16]

The CGS also highlights the use of natural gas to produce hydrogen, which results in the need to capture CO_2 using CCUS technologies and infrastructure. The Committee on Climate Change has identified low-carbon hydrogen with CCUS as one of the main options for the decarbonisation of buildings and industrial clusters.[17] To enable a hydrogen shift that facilitates meeting the 2050 target, the CCC states that it will be vital to undertake CCUS demonstrations in the 2020s. Without action now, it will not be possible to assess the feasibility and cost-effectiveness of large-scale decarbonisation using hydrogen.[18] The Oxburgh report also highlighted the importance of timely CCUS demonstration, and proposed hydrogen as a solution to the decarbonisation of heating.[19] Furthermore, Government has recently initiated a CCUS Council (chaired by Rt. Hon. Claire Perry, MP; Minister of State at BEIS) and a CCUS Cost Challenge Task Force. Cadent is an invited member of both groups.

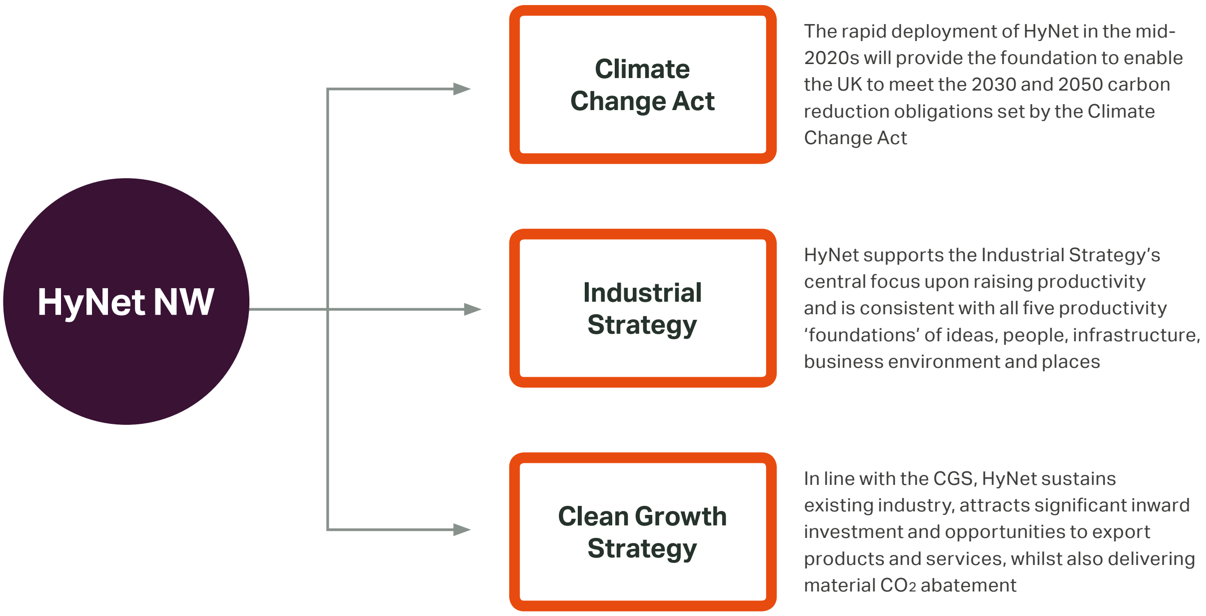
The proximity of HyNet NW to the nearby Liverpool Bay Oil and Gas fields, is such that it represents the UK's lowest cost location for CCUS. Producing low carbon heat at low cost is central to HyNet's 'philosophy' presented in Section 2.1, which also highlights the 'no regrets', low risk but innovative nature of the Project.

Alongside heating, the CGS also acknowledges the challenges presented by the need to decarbonise transport in order to meet the Government's 2050 obligations under the UK Climate Change Act. Consequently, a vision of how this can be achieved, by extending the HyNet NW Project, to deliver new infrastructure across the heating, transport and electricity sectors, is presented in Section 3.2.

At the same time, the CGS notes the potential not only for the creation of whole new industries, but for safeguarding and transforming existing industries as we move towards a low carbon economy. As described further in Section 3.3 (and in more detail in a separate report by AMION Consulting), this emphasises the economic benefits that will be brought about by HyNet NW, not only to the North West of England, but to the wider UK as a whole.[20]

The consistency of the HyNet Project with the above key Government strategy and policy initiatives is demonstrated in Figure 4.1.

Figure 4.1: Consistency of HyNet with Government Policy



5.0 Pathway to Deployment

The assumption is that HyNet NW will be financed by the private sector. This can only happen, however, if appropriate policy mechanisms are in place to provide income at a level which justifies investment. Considerations which guide the design of such mechanisms are explored in Section 5.1, and a proposed framework for delivering HyNet NW is described in Section 5.1.2. This analysis is informed by a recent study undertaken by Frontier Economics on behalf of Cadent.[21]

Alongside the funding challenge, in advance of reaching a final investment decision (FID) all remaining technical challenges must be addressed (as is described in Section 5.2) and wider project risks systematically mitigated. Taking into consideration these challenges and the timescale for their resolution, a project development timeline is presented in Section 5.3.

5.1 Funding

5.1.1 Key Funding Considerations

There are three key funding considerations in respect of the HyNet NW project, which can be summarised as follows:

1. Until energy markets fully internalise the impact of carbon dioxide on the environment with an appropriate carbon price, substitution of natural gas for heating with either hydrogen or electricity will be more expensive than the status quo and hence requires support.

   In the electricity sector, the Government has used a variety of policy mechanisms over the last decade to support meeting UK's targets under the EU 'Renewable Energy Directive'. These include the Renewable Obligation (RO), Feed-in Tariff (FiT) and the Contracts for Difference (CfD) regime. The CfD, coupled with Government support to help manage construction and other risks, is also being used to support the development and construction of Hinckley C Nuclear Station. Electricity consumers have funded this development, and critically, this support has helped bring down costs over time, and therefore the levels of support required for solar PV, and onshore and offshore wind. Section 2.4.2 suggests that a similar cost reduction pathway will exist for Hydrogen and CCUS. The latter is being explored by the Government's CCUS Cost Challenge Taskforce. An equivalent to the RO, FIT and CfD does not exist for low carbon heat generation from gas.

2. The support mechanism for HyNet NW must be in place by early 2021 which, given the overcrowded parliamentary agenda, means that the approach used must not require primary legislation.

   This timescale is driven by the need to align the delivery of the Project with both the decommissioning of the Liverpool Bay oil and gas fields and the timetable for fixing the 'RIIO 2' Price Control mechanism for gas distribution for 5-8 years from 2021.[22]

   Alignment of the project with field decommissioning allows maximum re-purposing of the existing offshore assets, considerably reducing costs. Field decommissioning costs are shared between Government and the field owner and already appear on the former's balance sheet. Consequently, the potential to save or defer an element of these costs may both function as an incentive to Government to act within the current window of opportunity and provide one source of funds to support the project.

   The RIIO 2 Price Control mechanism for gas distribution is currently being consulted upon and reviewed by Ofgem and will be reset in April 2021. As described in Section 5.1.2 this may well be an opportunity to create a support mechanism for HyNet NW, which does not require primary legislation.

   As described in Section 4.0, the timescale and scope of the HyNet Project is consistent with the recommendations of the CCC, which recommends that the first CCUS infrastructure is put in place in the 2020s to demonstrate CCUS, provide a foundation upon which to deliver CCUS at scale in the 2030s and to provide the learning required to reduce costs.[23] In support of this goal, HyNet NW will be operating by 2025 if a FID is made before the end of 2022. In addition, the CCC recommends that attention is focussed on reducing emissions from heat and from transport The HyNet Project meets these needs at low cost.

3. The source of funds providing support must be appropriately 'socialised' across consumers and/or taxpayers

   CO_2 emissions reduction is a common good and the principle of socialisation of support costs has been applied in most initiatives since the Climate Change Act was passed in 2008. The mechanisms used to support the production of low carbon electricity described above are socialised in this way. The funds for other mechanisms, such as the Renewable Heat Incentive (RHI), have similarly been sourced from taxpayers or spread across all energy users.

   In addition to this point of principle, the participation of industrial manufacturing plants in this first phase of the HyNet Project is key to reducing costs, by avoiding the need to deploy expensive underground hydrogen storage infrastructure. Many energy intensive industries compete in global markets and could become uncompetitive if socialised support is not available.

In addition to the above considerations, the following should be noted:

- HyNet NW is a 'trailblazer' project, creating CCUS and hydrogen infrastructure which enables low carbon gas to be used alongside electricity to meet UK decarbonisation targets. The support mechanism for HyNet need not be the same as for subsequent projects and project extensions; and

- The extent to which funding is required is highlighted in Section 2.3 in respect of the differential between the LCoH and the current price of natural gas, which is around £23/MWth. Funding for both the Capex and Opex elements represented by this differential must be identified.

5.1.2 Proposed Funding Model

Frontier Economics, in the aforementioned study for Cadent, observe that economic theory propounds the principle that the following two groups should provide the funding needed to support emissions reduction projects: [24]

1. The multiple beneficiaries of conversion to hydrogen; both those benefiting immediately and those benefiting later as a result of the project. These include:

   a. The wide range of future beneficiaries (across the wider UK and across multiple sectors) as a result of 'learning' from a FOAK project, the enabling of project extensions and a reduction in the need to invest in emissions reductions elsewhere in the economy.

   b. Electricity customers, due to the reduction in requirement for electricity network reinforcement, otherwise required by electric heat pumps or electric vehicle charging in the area. Furthermore, as described in Section 3.2, any CCUS infrastructure created for HyNet is likely to be made available for future power generation projects, thus reducing the cost of further decarbonising electricity generation; and

   c. Those in the locality of the project, who gain from improved air quality, particularly as a consequence of a reduction in emissions from transport, and a greater level of inward investment into the local economy.

2. The parties responsible for 'pollution' from current gas use:

   a. All natural gas users emit carbon and the emissions from all consumers are reduced by the use of a hydrogen blend; and

   b. As a society there is a need to reduce the carbon emissions associated the products we use. A successful industrial strategy enables industry to play its part in this. In this case, the system benefits associated with hydrogen volume and operational flexibility provided by industrial participation should be recognised.

The previous Clusters study suggested that the most likely source of funds was via Cadent's Regulated Asset Base (RAB) under the forthcoming RIIO2 period from 2021-2026/29. This appears to be supported by Ofgem's recent RIIO 2 Framework Consultation which states that, in terms of its support for future innovation, "it may now be appropriate to re-focus support towards larger-scale, whole system oriented projects".[25]

However, technically this approach may be interpreted as only socialising costs across those responsible for local emissions, ignoring the fact that the beneficiary groups are spread across the whole UK. Accordingly, Ofgem's Consultation notes the particular difficulties associated with funding projects where benefits accrue to parties beyond the innovator, or where co-ordination is required.[26] Consequently, to reflect the benefits to groups outside of the North West, funding nationally at GDN level via coordination of all GDNs or via National Grid's gas transmission charges, should be considered.

As the development of HyNet will provide benefits across sectors and regions, this also justifies the use of Government funding, as has been used by BEIS to support decarbonisation of heat via the RHI and for various FOAK projects in the form 'innovation' support. Taking into consideration wider factors such as distributional fairness, affordability, and political constraints, however, this is likely to only be suitable for certain elements of the Project.

Ultimately, therefore, funding for the Project might be primarily sourced from customer energy charges. Government support for conversion costs of the participating industries may also be appropriate, which would result in the overall funding structure presented in Figure 5.1. The costs of industrial conversion to Government might be reduced by industry's avoidance of the need to purchase EU Allowances (EUAs) under the EU Emissions Trading Scheme (ETS).

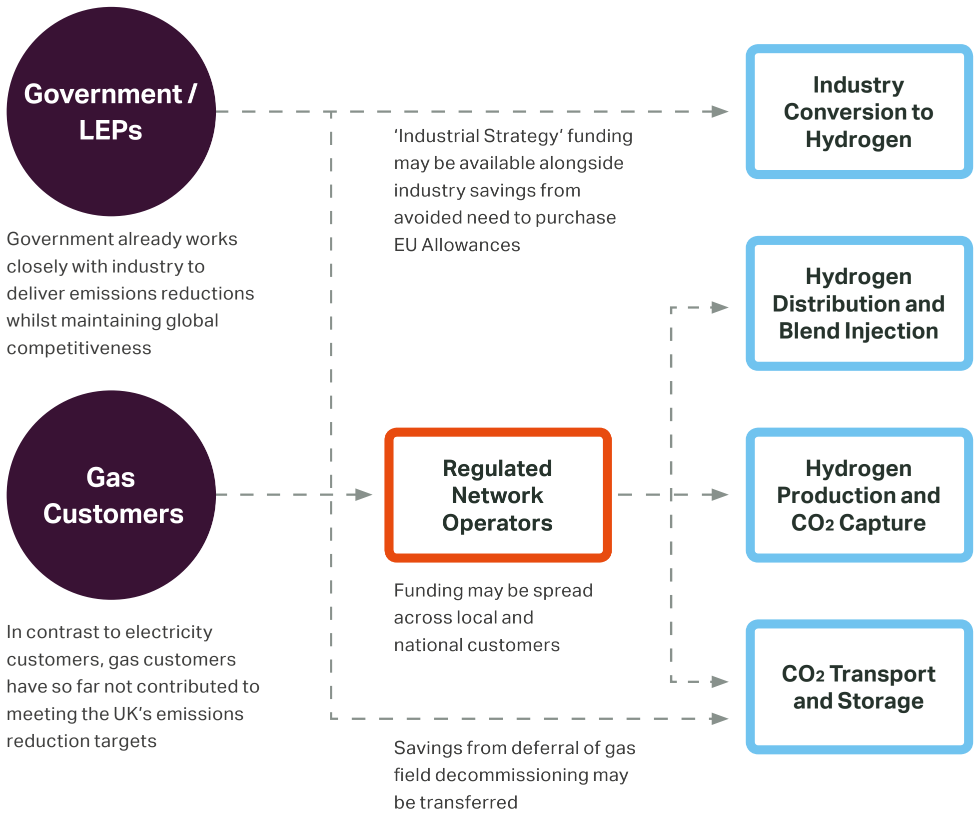
Ofgem's RIIO 2 consultation highlights the need for increased alignment of funds to support critical issues associated with the energy transition.[27] It also calls for greater co-ordination of public sector innovation funding and support. To enable projects such as HyNet NW, therefore, Government will need to lead in terms of policy support and relevant legislation regardless of the funding delivery arrangements used.

Within this approach, options for overall project co-ordination include pursuing a framework similar to that recently used to fund the Thames Tideway Tunnel (TTT). This would bundle delivery and operation of activities together and fund them through RAB-financing. Under this kind of structure it would be important to maintain the practical risk separation of the hydrogen production, CO_2 capture and distribution from CO_2 transport and storage.

Figure 5.1 represents one funding option; alternative combinations are also possible. For example, a hybrid funding solution could consist of gas customer funding for the hydrogen and CO_2 capture elements of the project, and Government funding for the CO_2 transport and storage and industrial conversion elements. In the context of CCUS, however, it is important to note that experience has demonstrated (in the CCS Commercialisation Programme, which concluded in 2015) that assuming Government does not provide related funding, it will need to take on the key risks for CCUS chain failure, as this cannot be borne by the private sector, as acknowledged by the Oxburgh Report.[28]

As described further in Section 5.3, ongoing work and engagement with both Ofgem and BEIS is required to design the most suitable funding framework.

Figure 5.1: Proposed Outline Funding Model



5.2 Demonstration Testing to Remove Technical Uncertainties

At this stage, some uncertainties exist in relation to the costs and performance of hydrogen production, hydrogen distribution via dedicated pipeline and CO_2 transport and injection for storage. The primary route to reduce these uncertainties to a level at which HyNet can reach FID is via further analysis, conventional engineering activity and a limited amount of practical testing.

Prior to FID, however, aspects of hydrogen combustion require demonstration, as described in Section 5.2.1. The previous Clusters study provided detailed information in relation to a range of technical barriers and opportunities associated with converting different industrial heating applications (i.e. boilers, kilns, furnaces, gas turbines and reciprocating engines) from natural gas to 'high' hydrogen. This report focuses only on the plant types included in the Reference Project described in Section 2.2.

At the same time, as described in Section 5.2.2, injection of a hydrogen blend into a public network also requires demonstration.

5.2.1 Supply of High Hydrogen to Industry

The HyNet project has undertaken extensive engagement with industry along with further engineering work to that presented in the Clusters study. This has demonstrated that there are no fundamental technical 'show-stoppers' to the use of 'high' hydrogen in most industrial applications. Indeed, many burner manufacturers and original equipment manufacturers (OEMs) are experienced in designing and developing equipment for operation on fuel gases with high hydrogen content. Similarly, there are already some industrial sites, including in the North West, which have already converted to hydrogen in such a way.

To convert to hydrogen more widely, operators of industrial manufacturing sites require confidence that a robust evidence base exists to demonstrate that conversion is technically possible. Consequently, a practical validation programme is required.

For many of the potential technical issues, evidence is available, for example from the upstream supply chain or experience from other sectors, to provide the necessary confidence. Key parts of the chemicals and refinery industries have operated successfully and safely with hydrogen for many decades. For other constraints, there is a need to provide specific evidence to provide the required confidence. This includes practical validation programmes to address uncertainties relating to:

- Specific impacts on plant performance or efficiency;
- Whether emissions of pollutants, such as NOx can be managed within the constraints of existing limits and without incurring prohibitive costs; and
- Any impacts on manufactured products, which is particularly relevant for direct-fired processes, such as kilns and furnaces.

In many cases, actual demonstration, either at existing industry sites or using suitable test rigs, must be undertaken. Some such tests might be supported by the forthcoming Phases 2 and 3 of BEIS' Fuel Switching Programme or possibly the industrial sector work package of BEIS' hydrogen for heating ('Hy4Heat') Programme.[29]

The extent and ease to which industry can be converted varies across the different applications. Whilst there appear to be no insurmountable technical barriers to converting existing kilns, furnaces and particularly boilers to high hydrogen, reaching such levels in gas turbines and engines is a far greater challenge.

Of those industry sites included within the scope of the HyNet Reference Project described in Section 2.2, none is host to a process-critical turbine or engine. However, as the Project is extended in the future, inclusion of such sites will be inevitable and so the technical barriers will need to be addressed as part of future phases. Internationally there has been considerable work on large scale gas turbines operating on hydrogen by OEMs which provides confidence in fundamental feasibility. There will be a need to develop power generation and CHP solutions at the scale required for industry. If Government puts in place a suitable mechanism to support hydrogen and CCUS (as discussed in Section 5.1.2), then the related market demand for machines fuelled by hydrogen will enable OEM investment in suitable development and testing programmes to modify or to bring relevant machines to market.

It is also worth noting that such technical constraints will be amplified if there is a switch to 100% hydrogen, as is proposed in other major hydrogen projects in the UK. To enable industry adoption of hydrogen as a fuel, the existing supply of natural gas needs to be maintained (at least in the short to medium term) because:

- A phased introduction of hydrogen, which demonstrates higher levels of (and potentially full) hydrogen, is required to facilitate industry buy-in;
- Some industrial applications will never be able to run on full hydrogen without some proportion of natural gas in the fuel gas; and
- Industry will have insufficient confidence, at least in early stage projects such as HyNet, in hydrogen system resilience.

This rationale echoes the HyNet Project Philosophy described in Section 2.1.

5.2.2 Demonstration of a Hydrogen Blend in a Public Network

The HyDeploy project is seeking to establish a maximum permissible hydrogen concentration in a blend and it is expected that a blend concentration between 10 and 20%$_{vol}$ will be possible.[30] The area covered by the blend to be injected into the gas network as part of the HyNet Project will unavoidably include both gas turbines and engines, most of which can only run on lower hydrogen concentrations. Consequently, if suitable modifications are not economic, such plant will need to be isolated and fed with gas with a lower concentration of hydrogen.

The immediate need is to establish and demonstrate acceptable levels of hydrogen. OEM data suggests that many gas turbines can function effectively on up to 10-20%$_{vol.}$ blends of hydrogen. OEMs such as General Electric, Mann Group and Solar/Turbomach are able to provide guarantees for their gas turbines burning fuel gases, in some cases, containing up to as high as 60%$_{vol.}$ hydrogen, whilst Siemens' gas turbines are also generally proven on relatively high proportions of hydrogen. Analysis of the major gas turbines currently in operation at sites within the HyNet area to be supplied by the blend, suggests that all such machines could, in principle, operate without significant modification.

For gas engines, there are particular challenges and issues, such as greater NOx formation, increased flame speed, premature ignition and backfiring as the hydrogen level is increased, which all require management. Work is currently being undertaken, including practical testing, to establish the extent to which hydrogen blends can be accommodated in an existing machines in light of these fuel gas attributes.[31] In the event that it is not possible to accommodate hydrogen at the blend network level in existing machines, there are number of potential options to manage the issue:

- Lowering the hydrogen content to acceptable levels at the point of use

  Hydrogen extraction from a blend is technically proven. Under this approach, hydrogen might be either injected back into the network, or else it might facilitate wider supply of hydrogen for vehicle transport at a variety of locations at relevant locations along the distribution network.

- Encouraging the supply of new machines able to operate on a blend

  Engagement with OEMs has demonstrated that there are no inherent blocks to manufacturing engines able to operate on a hydrogen blend, but that the market to provide such machines has not existed to date. In fact, gas engines are available which have functioned safely and efficiently on coke oven gas containing up to 51% hydrogen. Alternatively, gas turbines, or in time, fuel cells might be adopted. The HyNet NW Project could therefore provide an incentive to drive the development and availability of relevant machines to support wider deployment of a hydrogen blend injected into the network.

The extent to which either of these approaches are adopted depends on a range of external factors; not least the extent of available funding to support HyNet NW. Furthermore, it is likely that the solution will be site specific and dependent on the age of machine and the duty required. For example, sites with machines reaching end-of-life may be able to justify investment in a new machine and a site located adjacent to an existing vehicle refuelling station might be more suited for hydrogen removal from the blended gas.

The HyDeploy project, involving injection of hydrogen into a private gas network, continues to provide a wealth of evidence in relation to how all technical and regulatory barriers can be overcome, in respect of the supply of a hydrogen blend to domestic (and most commercial) customers.[32]

The injection of a blend will next need to be demonstrated on a 'public' network to give full confidence to Ofgem, the Health and Safety Executive (HSE) and to the customers to be supplied by HyNet NW, that hydrogen can be used safely in a public network. A follow on proposal, 'HyDeploy 2', is being developed to deliver this and provide the necessary evidence, potentially involving all Gas Distribution Network Operators (GDNOs).

5.3 Development Programme

The aim is to have a cost effective project operating by 2025 and for this project to be structured to provide CCUS and hydrogen infrastructure which enables low carbon gas to make a major contribution to meeting the UK's emissions reduction targets and creating value in the 2030s. This is in line with the CCC's recommendations for the first CCUS projects to be operating by the mid-2020s and Government's aspiration to have in place a CCUS deployment pathway which can deliver CCUS in bulk by the 2030s, assuming this is cost-effective.

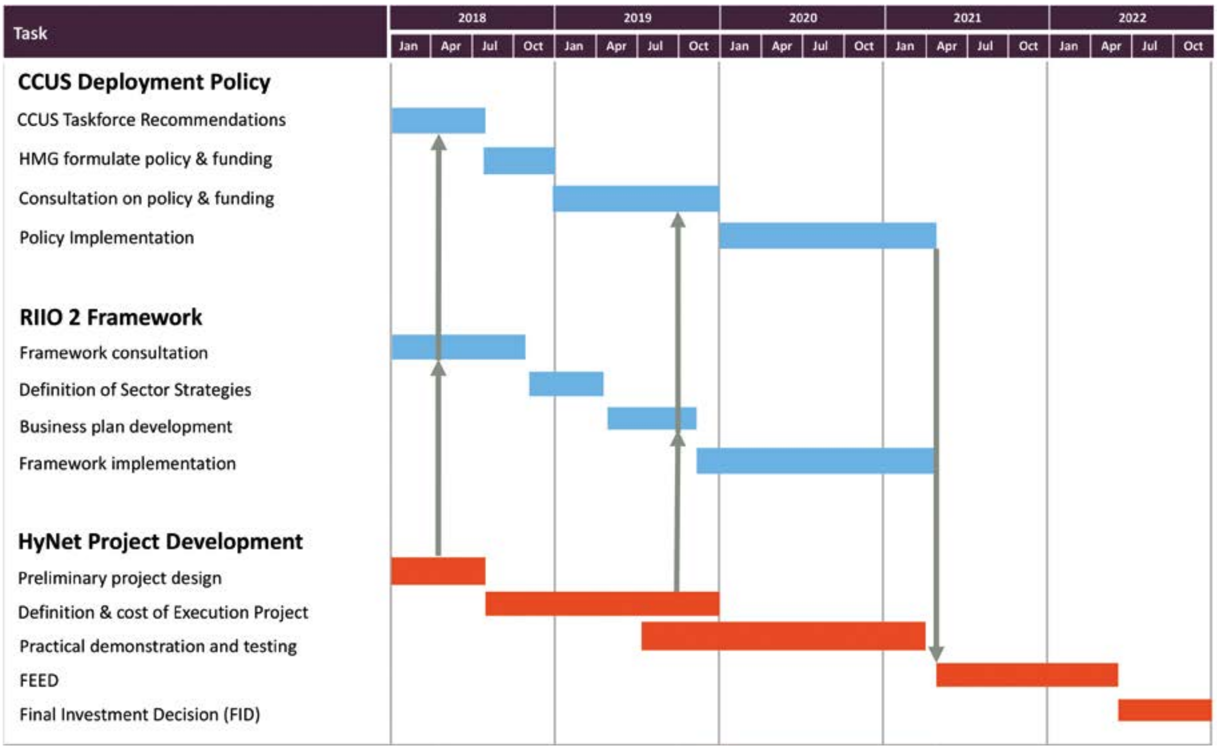
To enable deployment in the mid-2020s will require FID by the end of 2022 at the latest. As mentioned above, this date is also crucial to link the Project to the closure date for the Liverpool Bay gas fields, enabling lower costs by re-purposing the offshore facilities. To reach FID at this point, the funding mechanisms to justify investment in the project must be in place.

As described in Section 5.1.2, Ofgem has started to consult upon and review the RIIO 2 Price Control framework for gas distribution and transmission companies that will be adopted from April 2021 for 5-8 years and the critical points on the programme for this are very important. As shown in Figure 5.2, which presents the timeline for major decisions, key points in establishing a suitable funding framework occur in 2018 and 2019. Government discussion with Ofgem, to confirm that the project may be funded under the RIIO framework, is an essential requirement.

In principle, the CO_2 transport and storage costs (alongside the hydrogen production and transport costs) could be funded under the RIIO 2 Price Control Framework. If this is contemplated, then it would need to be agreed in principle before the end of 2018 and then incorporated into business plans during 2019. However, the alternative of funding CCUS infrastructure separately is receiving attention from the Government's CCUS Cost Challenge Task Force. If this route is adopted then the source of funds and mechanism must be developed and put in place on the same timeline as RIIO 2. The latest that either funding mechanism is likely to be fully operational is April 2021.

The willingness of the private sector to fund significant development spend, however, will depend on the assurances that can be put in place before April 2021. In particular, certain consenting and pre-FEED activities, along with the practical demonstration and testing programme described in Section 5.2, will need to start before April 2021 in order to efficiently dovetail to the Hamilton field closure plan.

Figure 5.2: Decision-making Framework Required for FID by 2022



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Notes

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