Appendix A21 – Final Pre-FEED Report

Northern Gas Networks

East Coast Hydrogen - Pre-FEED Study

Pre-FEED Report

Reference: 293805-ARUP-PFR

NGN Reference: REP 009

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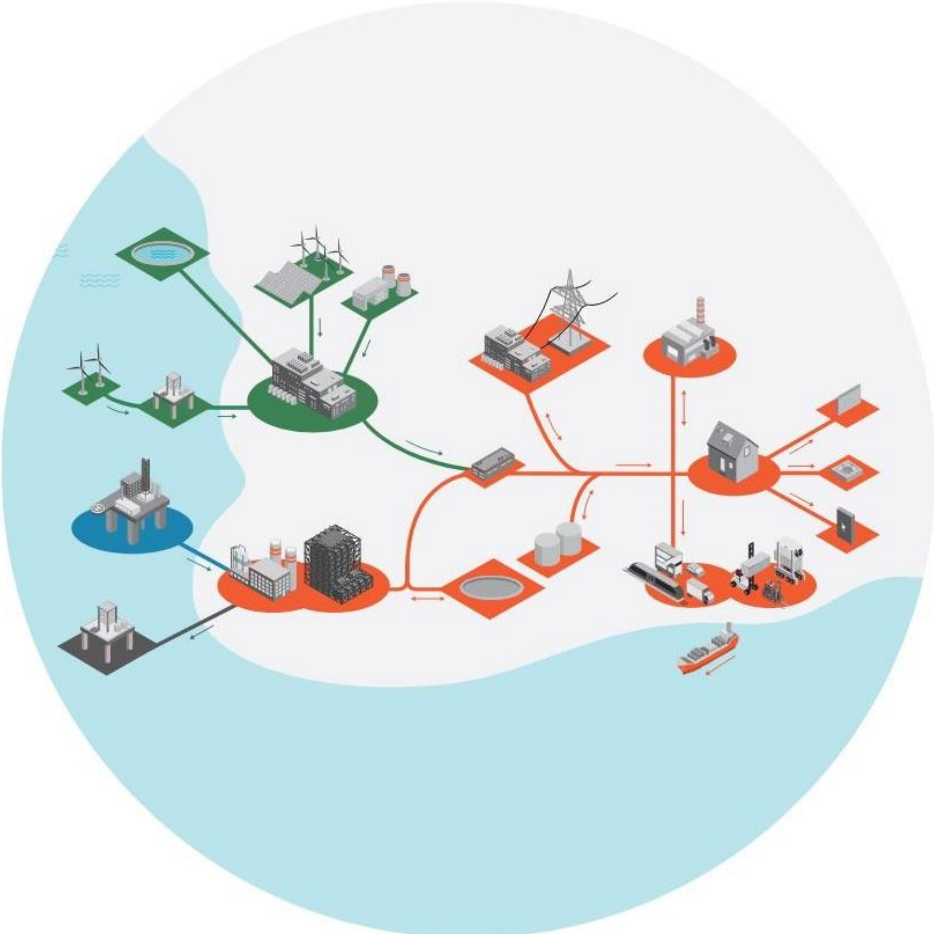

Job number 293805-00

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Contents

Acronyms

Name	Acronym
Above Ground Installation	AGI
East Coast Hydrogen	ECH
Front End Engineering Design	FEED
High Pressure	HP
Hydrogen	H2
Low Pressure	LP
Medium Pressure	MP
Multi Criteria Analysis	MCA
Capital Expenditure	CAPEX
Gas Distribution Network	GDN
Health and Safety Executive	HSE
Local Transmission System	LTS
Natural Gas	NG
Quantified Risk Assessment	QRA

Name	Acronym
National Gas Transmission	NGT
Department of Business, Energy & Industrial Strategy	BEIS
National Transmission System	NTS
Net Zero and Small Projects	NZASP
Northern Gas Network	NGN
Department for Energy Security and Net Zero	DESNZ
Town and Country Planning Act	TCPA
Dangerous Substances and Explosive Atmospheres Regulations	DSEAR
European Union	EU
Return on Investment	ROI
Pressure System Safety Regulations	PSSR
Pipelines Safety Regulations	PSR
Institution of Gas Engineers and Managers	IGEM
Annual Quantity	AQ

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Executive Summary

Connecting UK industry with low carbon hydrogen production is a key enabler for the UK decarbonising and achieving net zero by 2050. About 25% UK emissions come from industry, with the majority of emissions coming from industrial clusters (Zero Carbon Hubs, 2023). East Coast Hydrogen (ECH) will connect industrial clusters to a hydrogen transmission backbone, National Gas' Project Union, and a Northern Gas Networks (NGN) hydrogen distribution network.

The Pre-FEED study initially collated information to inform the network development. This included production, demand and storage figures. These data were then further validated by stakeholder engagement which ran throughout the project, to further strengthen the understanding of the network requirements.

The project basis of design was developed to understand the technical constraints which would be applied to the routeing study. A key focus of the project has been to repurpose as much of the pipeline infrastructure and Above Ground Installations (AGIs) as possible. A repurposing strategy was developed to understand the viability of repurposing assets. A transition process was also developed to understand how the network could feasibly be disconnected from the natural gas system to allow for hydrogen transport.

The route optioneering phase of the Pre-FEED study aimed to understand the viable pipeline connections which could be made between the production sites, storage and users. The routing was undertaken using an Artificial Intelligence routing tool, which considered multiple technical and environmental constraints whilst routeing options as well as developing complexity scores and capital costing for each pipeline. A selection process was then undertaken to assess the proposed routes, this considered the viability, cost and hydrogen transport of each route and cluster. The clusters were then scored based on the line complexity and cost to determine which were viable. Further to this, a phasing strategy was developed which accounted for when users might feasibly be able to accept hydrogen and prioritised the clusters which scored the highest during the assessment phase.

Ensuring that there was continuity of natural gas supply where required was another key aspect of this project, network analysis was undertaken to verify this could be achieved with the proposed network, allowing for reinforcements by new-build pipeline where this was not achievable.

Outline designs of pipelines and AGIs were created to understand the key differences between natural gas and hydrogen transport infrastructure. This also informed the capital cost estimations which utilised NGN construction experience to develop costings.

The project concluded by outlining the next steps which would be required during the FEED stage of the project and developing a scope document and programme of how this would be delivered.

1. Introduction

In 2020, the UK Government released their 10-point plan for the UK to become net zero by 2050. The government has been continuing to support the growth of a low carbon hydrogen network through the Net Zero Hydrogen Fund (NZHF) and the Hydrogen Production Business Model (HPBM). There is acknowledgement of the importance of a national distribution network to facilitate the adoption of this nascent industry. This has been outlined by the Department for Energy Security & Net Zero (DESNZ) in their Hydrogen transport and storage infrastructure: minded to positions which was published in August 2023 and the Pathway document which was later released in December 2023. The initial focus on this business model will be on large-scale pipeline infrastructure which transports hydrogen as a gas, to link hydrogen producers with users and storage.

The East Cost Hydrogen (ECH) project is being undertaken by a partnership of National Gas Transmission (NGT), Cadent and Northern Gas Networks (NGN). This Pre-FEED study has been undertaken to establish a feasible route for the conversion and development of a network to be utilised for the decarbonisation of industry and heating of homes and demonstrate this to Ofgem and DESNZ.

Arup were commissioned by NGN to undertake the study, the commission was to:

1. Carry out a pre-FEED study for the Eastern region, including “East Coast Hydrogen” (ECH) industrial cluster to support the Net Zero and Small Projects (NZASP) Reopener in subsequent project phases e.g., FEED study.
2. Identify the most efficient route to connect the region to the East Midlands Hydrogen Innovation Zone.
3. Enable conversion to 100% hydrogen heating for domestic users.

Other key elements of this scope included:

1. The transition processes.
2. Storage and network balancing.
3. Locations for pressure and compression where required.

ECH can utilise the existing natural gas assets of the North of England, including existing natural gas storage and potential hydrogen storage facilities. It will build on the hydrogen production in two of the UK’s largest industrial clusters in the and in turn ensure significant private sector investment in the UK’s industrial heartlands. ECH is a 15-year programme that will be carried out in multiple discrete phases to decarbonise industrial processes and domestic heating in the East Coast region. Proposed phases can be seen below:
Phase 1 - (2022 2026) - Completion of Pre-FEED, FEED Study and development of East Coast Cluster infrastructure
Phase 2 - (2024 2030) - Connection of Humber and Teesside clusters, and growth into Yorkshire and East Midlands
Phase 3 - (2028 2037) - Expansion from the industrial Clusters into Northern urban areas and the Midlands
Phase 4 - (2037+) - Connection of the network into further regions and future growth opportunities

2. Purpose of Document

This report outlines the key outcomes of the Pre-FEED study and is a signpost document to the deliverables produced in the stages of the Pre-FEED study.

A brief overview of the stages and respective reports that is covered by this document can be found in Table 1. The content of each documentation is then elaborated in the subsequent sections of the report.

Table 1: Overview of the deliverables of the programme

Stage	Documentation	Purpose
Stage 1a Information Gathering	• Demand report 293805-ARUP-DMS. • Storage report 293805-ARUP-STS • Production report 293805-ARUP-PRS	Identification of demand, storage and production requirements to inform network design, updated throughout the project.
Stage 1b Preparation for Optioneering	• Project execution plan 293805-ARUP-PXP	Project execution plan updated throughout the project.
	• Initial Modelling brief 293805-ARUP-IMB	Modelling inputs to analyse repurposing feasibility of individual pipelines.
	• Decisions, assumptions and risk register	Recording of decisions, assumptions and risks, updated throughout the project.
	• Re-purposing strategy 293805-ARUP-RPS	Basis of repurposing existing assets.
	• Existing network study 293805-ARUP-ENS	Analysis of the existing network with a view to repurposing.
	• Options design basis 293805-ARUP-ODB	To set out the inputs and strategy to be utilised in the project optioneering stage.
Stage 2 Optioneering	• Options network modelling	Reporting on the options assessed, methodology, findings and recommendations.
	• Options and phasing study report 293805-ARUP-OSR ○ Network concept ○ Routing corridors ○ Transition and phasing plan ○ Storage and network balancing ○ Pressure and compression ○ Network interface ○ Generic challenges ○ Project challenges	Articulate the project infrastructure requirements of the proposed network, how this is envisaged to be developed and key challenges to address in the remainder of the project.

Stage	Documentation	Purpose
	• Challenges Modelling Brief	Identification of requirements for modelling work to resolve the project challenges identified.
Stage 3 Preferred Solution Design/Modelling	• Final Pre-FEED report 293805-ARUP-PFR ○ Final phasing plan ○ Town pilot interface ○ Outline pipeline design ○ Outline facilities design ○ Project capital cost	Summary of the findings of the Pre-FEED study. Signpost document to the deliverables produced. Coordination of final network selection and demand and production analysis. Identification of how the proposed network interfaces with the towns pilot. Descriptions of outline designs and identification of the investment required to deliver the infrastructure.
	• Engineering justification paper 293805-ARUP-EJP	To support Net Zero ASAP (NZASAP) reopener
	• Full need case 293805-ARUP-NCD	To support Net Zero ASAP (NZASAP) reopener
	• Delivery plan	Input into document to support Net Zero ASAP (NZASAP) reopener
	• Demonstration of net benefit to consumers	Input into document to support Net Zero ASAP (NZASAP) reopener
	• Cost Benefits analysis	Input into document to support Net Zero ASAP (NZASAP) reopener
Stage 4 **FEED** Preparation and Final Deliverable	• FEED scope 293805-ARUP-FEED	Identification of scope of work for the FEED study.
	• FEED Programme	Plan and timetable for the scope of work for subsequent stages of the project.
	• Project capital cost	Estimate of the likely cost of carrying out the FEED study based on the Scope
	• Lessons learnt register 293805-ARUP-LLR	Identification of lessons learnt to inform the later stages of this project and others.

3. Stage 1a - Information Gathering

3.1 Demand Report

The purpose of the demand report (293805-ARUP-DMS) is to describe the data collection and processing stages which have been undertaken to provide the modelling inputs for the East Coast Hydrogen project. This document also outlines the assumptions which have been made up to the stage of issue, which are also captured in the project assumptions register.
The report is segmented as shown in Figure 1.

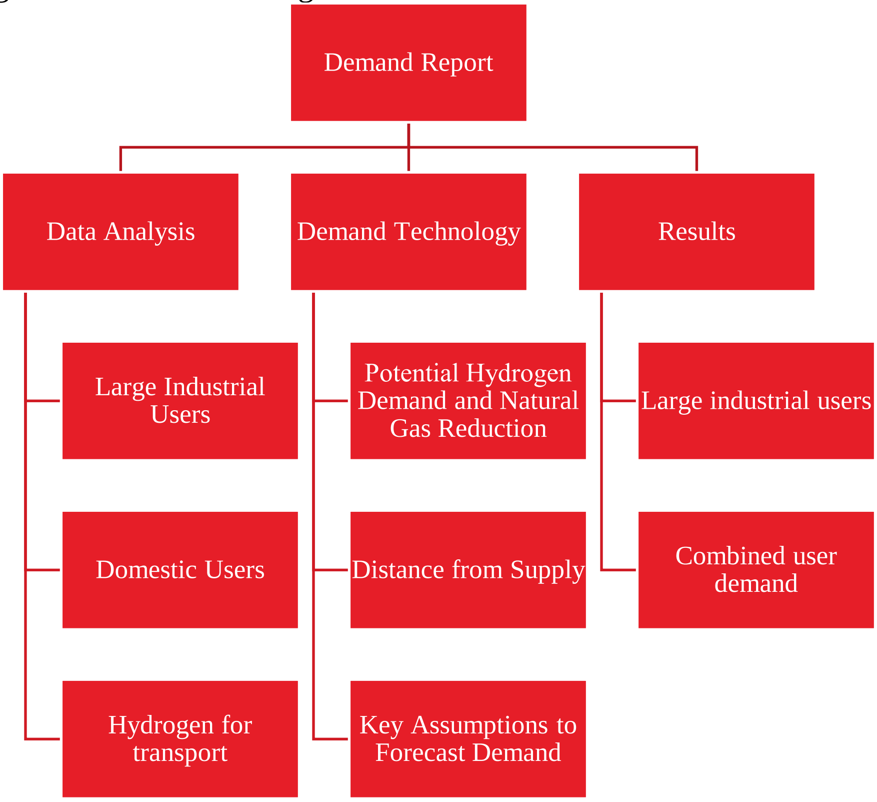


Figure 1: Structure of the Demand report.

3.2 Production Report

The purpose of the production report (293805-ARUP-PRS) is to describe the data collection and processing stages which have been undertaken to provide the hydrogen production modelling inputs for the East Coast Hydrogen project. This document also outlines the assumptions which have been made up to the stage of issue, which are also captured in the project assumptions register.
The report is segmented as shown in Figure 2.

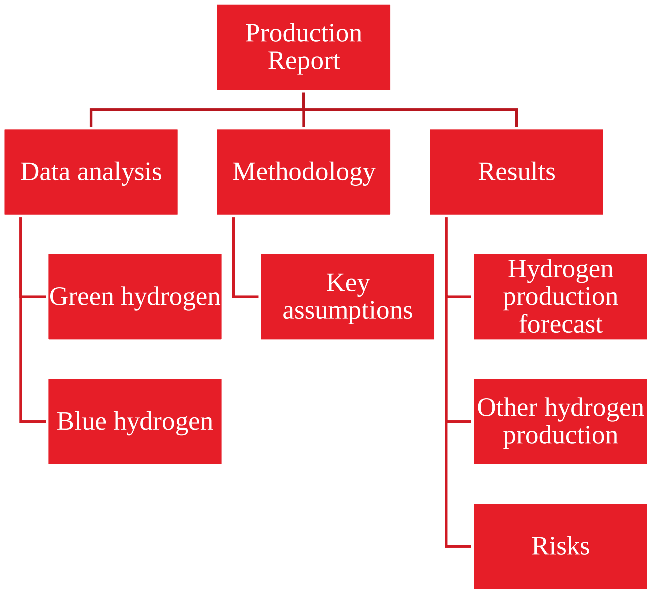


Figure 2: Structure of the Production report.

3.3 Storage Report

The purpose of the storage report (293805-ARUP-STS) is to describe the data collection and processing stages which have been undertaken to demonstrate the resilience of the future hydrogen transmission and distribution system and the external hydrogen storage availability and requirements. This document utilised data provided by NGN, supplemented with publicly available and internal data as a part of this assessment. This document also outlines the assumptions which have been made up to the stage of issue, which are also captured in the project assumptions register. The report is segmented as shown in Figure 3.

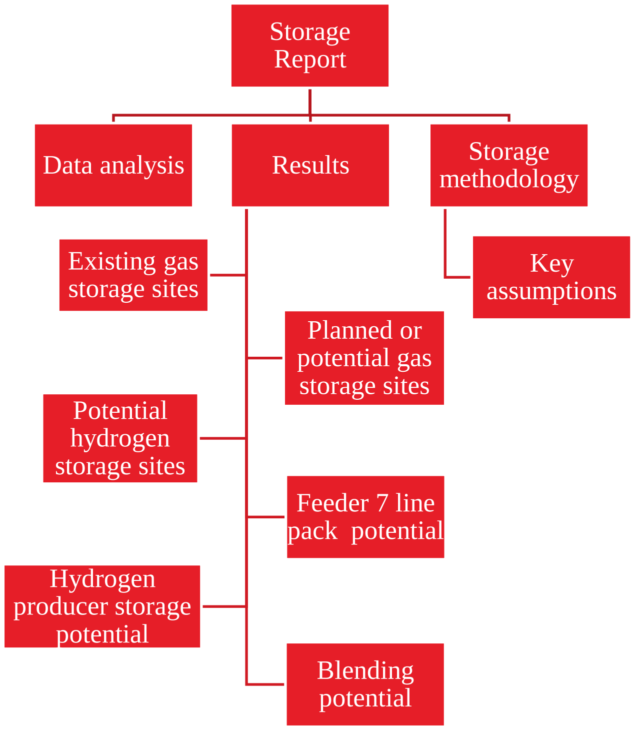


Figure 3: Structure of the Storage report.

4. Stage 1b – Preparation for Optioneering

4.1 Initial Modelling Brief

This initial modelling brief (293805-ARUP-IMB) identified the initial scenarios which were to be fed into the network modelling, based on the data collection and analysis undertaken at that stage. This allowed the viability of repurposing individual pipelines to be assessed and that information to be used within the optioneering. The demand modelling was an iterative process which carried on throughout the Pre-FEED project, but this document was the initial basis to begin modelling and start the network refinement.

The report is segmented as shown in Figure 4.

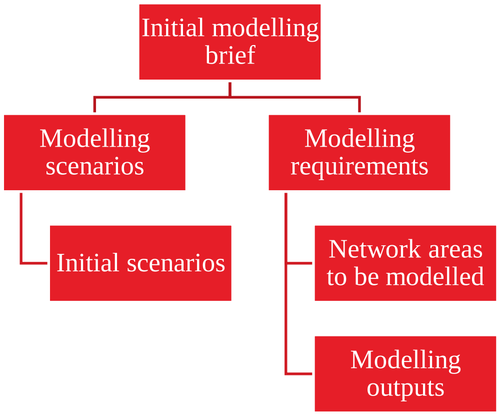


Figure 4: Structure of the Initial Modelling Brief.

4.2 Existing Network Study

This report (293805-ARUP-ENS) summarises the findings of the screening completed in the initial modelling brief and outlines the results of the modelling and screening assessment of the network for specific years based on agreed velocity criteria (Red: no capacity, Amber: potential capacity, Green: good capacity to switch). Analysis of the results for current flows and three specific years is shown with graphical summaries and mapping utilised to illustrate the results of this assessment. The purpose of this was to enable efficient identification of pipelines suitable for re-purposing and areas where new build will be required during the optioneering phase.

The report is segmented as shown in Figure 5.

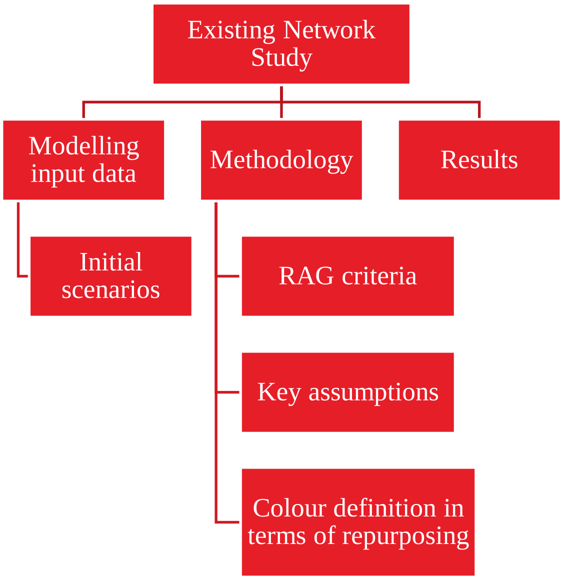


Figure 5: Structure of the report on Existing Network Study.

4.3 Repurposing Strategy

The repurposing strategy (293805-ARUP-RPS) outlines the intentions and philosophy of the East Coast Hydrogen project network development strategy. The strategy fed into the optioneering phase of the project, enabling the development of the proposed network and the phasing of this. The document covers the key considerations when assessing the suitability of assets for repurposing. This document also outlines the assumptions which were made up to the stage of issue, which are also captured in the project assumptions register.

The report is segmented as shown in Figure 6.

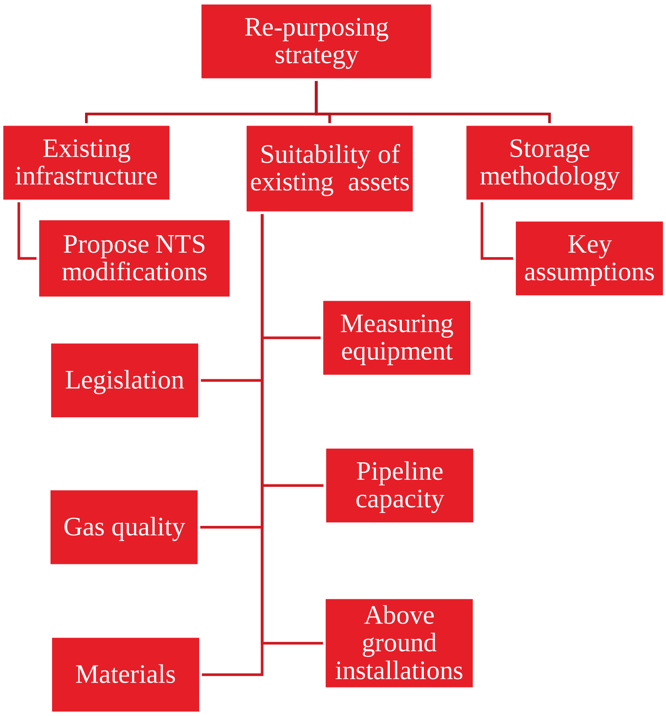


Figure 6: Structure of the Re-purposing strategy report.

4.4 Options Design Basis

The options design basis (293805-ARUP-RPS) outlines the strategy and approach for the network optioneering study. It summarises the base data and assumptions to be used including the demand and supply information.
The report is segmented as shown in Figure 7.

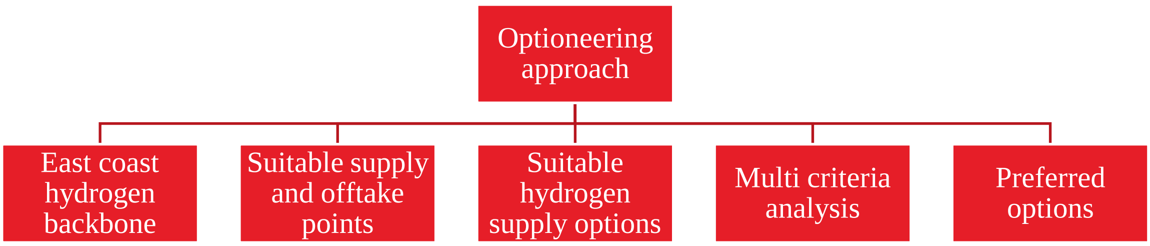


Figure 7: Structure of the Option Design Basis report.

5. Stage 2 – Optioneering

Following completion of the initial analysis for potential hydrogen production, usage and storage, this section of the work considered the options for developing the hydrogen network and expanding the availability of hydrogen throughout NGN's area. Options were developed for each stage of the project identified.

The first high-level project requirement was to connect the Humber and Teesside industrial clusters using existing NTS infrastructure. Extending from that backbone to reach the most effective uses and storage to match the production capacity throughout the project timeline.

The options and phasing study report combined the deliverables of this stage of the project.

5.1 Options and phasing study report

The Options and phasing report (293805-ARUP-OSR) is a key report which summarises the optioneering phase of the project. The document explores what the future, optimal network of hydrogen pipelines looks like for East Coast Hydrogen. It has funnelled the broad range of options into a preferred routing for the NGN region of East Coast Hydrogen to further develop. The report also details the information which was collated and the strategies used to inform the development of the proposed solutions, as well as the technical assessments which were undertaken to confirm the viability. The report is concluded with the final proposed solutions and the next steps which are required in the continuation of the network development.

This report expands on the topics shown in Figure 8.

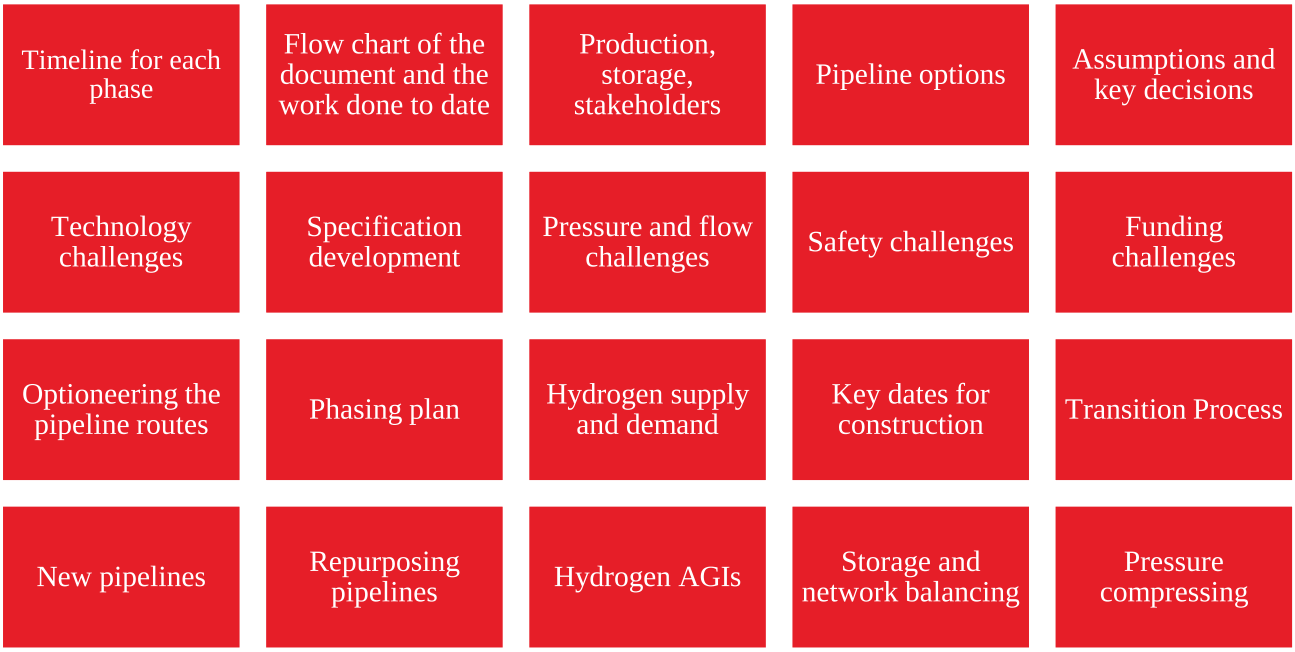


Figure 8: Content in Options and Phase study report

6. Stage 3 - Final Phasing Plan

To facilitate the transition to hydrogen fuel, pipelines will need to be constructed or repurposed in phases which allows natural gas supply to remain where required and reduce disruption to the existing network as much as possible. This section of the report details what will be included in each phase of the project.

6.1 Background

Figure 9 outlines the initial phasing plan for the ECH project, which was established in the Options Study and the associated report.

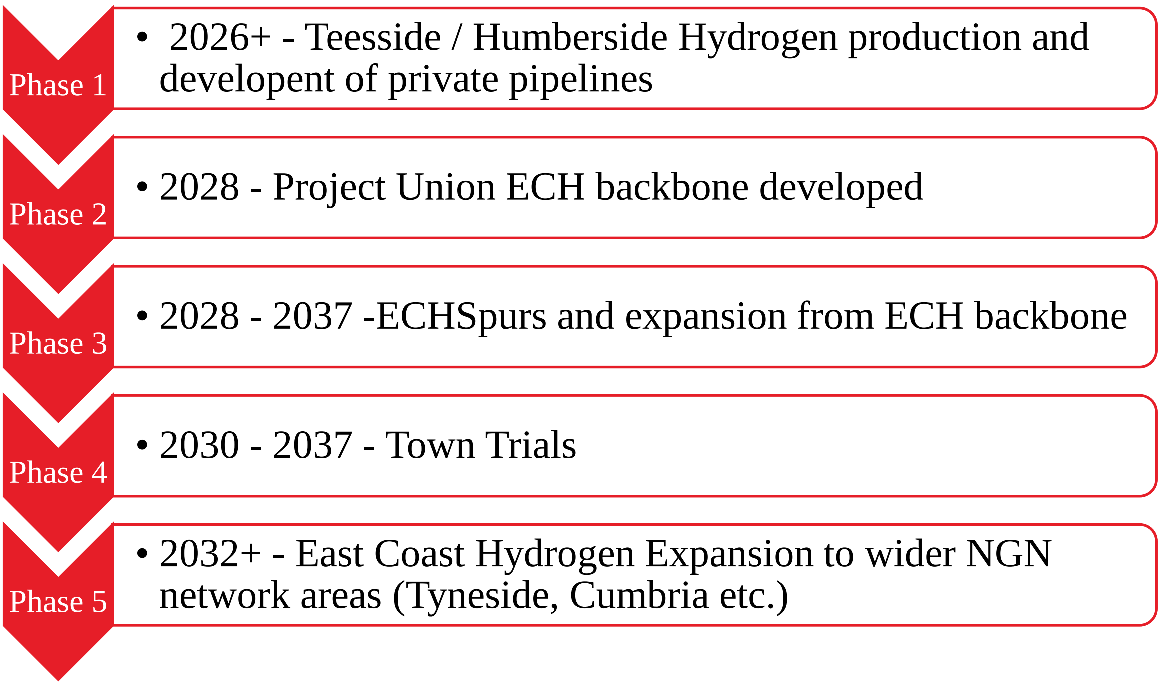


Figure 9: Initial ECH Phasing Plan

The initial phasing plan outlined above provides a broad scope for the future phases of East Coast Hydrogen. Starting with the initial generation of hydrogen and the establishment of private pipeline networks in key industrial clusters, the development of a fully connected network across the region, concluding in the expansion of the network to the wider NGN area. The phasing plan which follows aims to provide further detail to this initial phasing plan, with a particular focus on developing the dates within phase 3.

6.2 Methodology

In this section, Arup have aimed to rank the clusters in the project. This is to identify the high priority clusters, allowing these clusters to be scheduled for connection to the network earlier than the low priority clusters.

These rankings have been based on two key criteria. The energy demand for the cluster and the ease of constructability to connect the cluster to the network. The ranking of clusters based on these criteria were aggregated, producing a final ranking of clusters, which can be divided across the project timeline.

In some scenarios, individual clusters have been included earlier or later than suggested by their rank. Further information and justification for this is given.

6.2.1 Demand Ranking

For each cluster, of each area, the annual demand per meter of pipeline to be installed was calculated for the preferred scenarios, identifying where there may be 'easy wins' when compared to demand alone.

Initially, these only considered the length of new pipeline for each cluster. However, by applying a factor to the repurposed pipeline length, based on the expected cost of repurposing lines in comparison to new lines, and outlined in Table 2, the total pipeline length could be considered. This also allowed for the inclusion of clusters that are formed only of repurposed lines, for example, Tyneside cluster 1.

Table 2: Repurposed Line Factor for ECH Phasing

Repurposed Line Factor	
New Pipeline	1
Repurposed Pipeline	0.3

These results were ranked across all areas and are shown in Table 3.

Table 3: Demand Ranking for ECH Phasing

Cluster	Annual Demand / km (kWh/km)			Annual Demand / km Ranking		
	2028	2032	2037	2028	2032	2037
Teesside						
1 Hartlepool	6,565,091	6,709,664	6,709,664	18	19	20
2 Stockton & Billingham	17,144,160	26,542,031	26,542,031	8	9	9
3 Teesmouth	-	1,869,035	3,504,441	29	28	25
4 Middlesborough - Teesside South	60,033,162	125,676,547	126,812,208	3	2	2
5 Skinningrove	11,435,038	15,825,694	20,483,517	10	12	11
6 Greatham - Hartlepool South	10,647,620	144,421,017	144,421,017	11	1	1
Bishop Auckland to Pannal						
1 Newton Aycliffe & Bishop Auckland	2,082,463	5,175,058	8,291,940	23	20	17
2 Darlington	1,452,415	2,033,381	2,033,381	25	27	28
3 Spennymoor - Bishop Auckland North	8,358,297	8,358,297	8,358,297	14	16	16
4 Bedale - Thrintoft	37,657,405	120,969,803	120,969,803	5	3	3
5 Masham - Thrintoft	2,236,660	2,236,660	2,236,660	22	26	27
6 Ripon	4,761,387	4,761,387	4,761,387	20	21	22
7 Menwith Hill - Harrogate	1,417,297	2,263,829	2,263,829	26	24	26
8 Harrogate	1,499,667	3,593,969	5,426,484	24	23	21
Leeds / Bradford						
1 Leeds Ring Main	-	-	-	29	30	30
2 Huddersfield - Bradford	67,410,725	111,170,774	111,170,774	2	4	4
3 Bradford	8,337,053	12,722,792	12,722,792	15	15	15
4 Holbeck & Hunslet	38,152,311	76,304,622	76,304,622	4	6	8
5 Stourton - Leeds South	79,577,049	104,891,461	104,891,461	1	5	5
6 Leeds Central	-	-	-	-	-	-
7 Wakefield - Leeds South	12,190,433	18,285,650	18,285,650	9	11	12
8 Pontefract to Huddersfield	-	-	-	-	-	-
Towton to Asselby						
1 Selby	7,465,588	23,073,468	23,287,583	17	10	10
2 Goole	380,106	2,251,862	3,723,353	28	25	24
3 Howden	-	-	-	29	30	30
4 Selby & Knottingley	-	-	-	29	30	30
5 Tadcaster Sherburm	9,763,419	14,645,128	14,645,128	12	13	13
6 British Gypsum - Tadcaster Sherburn	4,151,456	4,151,456	4,151,456	21	22	23
7 Knottingley	23,702,295	48,560,493	85,944,530	7	8	6
Humber						

Cluster	Annual Demand / km (kWh/km)			Annual Demand / km Ranking		
	2028	2032	2037	2028	2032	2037
1 Howden	6,298,328	7,576,861	7,576,861	19	18	19
2 West Hull	7,637,183	8,239,927	8,239,927	16	17	18
3 Hull	28,498,791	62,985,664	76,685,628	6	7	7
4 East Riding and Storage	888,634	1,381,953	1,381,953	27	29	29
Tyneside						
1 Tyne & Wear	8,685,050	13,027,574	13,027,574	13	14	14

The demand data in the table above highlights the clusters which have the largest demand per kilometre of pipework. These clusters are mostly congregated in the large industrial areas on Humberside, Teesside and in West Yorkshire.

6.2.2 Constructability Ranking

The clusters of each area were also scored and ranked based on their constructability. This has been quantified using the penalty data extracted from the Continuum Optioneering modelling undertaken earlier in the project. The constructability data has been divided by the new pipeline length to allow results to be comparable on a per km basis.

In the table below, Humber cluster 3 and Tyneside cluster 1 do not have any penalty data from the Continuum modelling. This is because these clusters have been added at a later date and therefore will be modelled in a future phase, if required. For the purpose of this report, Humber cluster 4 and Tyneside cluster 1 have been left with a ranking of 1, as at this stage since they use a large amount of repurposed pipelines and have a strong business case. However, for Leeds-Bradford cluster 8, it is currently estimated that this line will have the longest new-build pipeline length in the project. Due to this, along with the majority of clusters in the area having a low rank, this cluster rank has been manually adjusted to the lowest rank available.

Table 4: Constructability Ranking for ECH Phasing

Cluster	Constructability		
	Continuum Penalty	Penalty per km	Penalty per km ranking
Teesside			
1 Hartlepool	42,266	5,953	16
2 Stockton & Billingham	17,589	2,513	8
3 Teesmouth	63,541	23,534	30
4 Middlesborough - Teesside South	126,873	8,458	19
5 Skinningrove	20,308	10,154	22
6 Greatham - Hartlepool South	28,152	10,427	23
Bishop Auckland to Pannal			
1 Newton Aycliffe & Bishop Auckland	47,342	1,734	5
2 Darlington	59,864	9,070	21
3 Spennymoor - Bishop Auckland North	17,619	2,202	7
4 Bedale - Thrintoft	59,809	5,201	13
5 Masham - Thrintoft	20,529	5,548	15
6 Ripon	85,719	5,133	12
7 Menwith Hill - Harrogate	36,058	4,051	10
8 Harrogate	97,192	12,622	25
Leeds / Bradford			
1 Leeds Ring Main	35,494	1,757	6
2 Huddersfield - Bradford	5,570	3,713	9
3 Bradford	167,661	19,495	29
4 Holbeck & Hunslet	20,666	15,897	27
5 Stourton - Leeds South	39,726	14,188	26
6 Leeds Central	39,325	-	-
7 Wakefield - Leeds South	42,523	8,678	20
8 Pontefract to Huddersfield	-	-	-

Cluster	Constructability		
	Continuum Penalty	Penalty per km	Penalty per km ranking
Towton to Asselby			
1 Selby	37,454	1,710	4
2 Goole	112,967	7,955	18
3 Howden	66,225	-	-
4 Selby & Knottingley	188,371	-	-
5 Tadcaster Sherburm	45,905	10,433	24
6 British Gypsum - Tadcaster Sherburn	18,174	1,699	3
7 Knottingley	147,354	5,498	14
Humber			
1 Howden	63,405	4,954	11
2 West Hull	233,626	16,224	28
3 Hull	224,708	6,106	17
4 East Riding and Storage	-	-	1
Tyneside			
1 Tyne & Wear	-	-	1

It can be seen from the rankings above, that the most constructable clusters are those which are situated in more rural areas, and therefore face lower construction penalties. The least constructable clusters are those located in highly urbanised areas, such as Leeds, Hull and Middlesborough.

6.2.3 Weighted Ranking

To provide a final ranking for each cluster, the demand rankings and constructability rankings were aggregated. The weightings which were applied to each ranking within the final rank is outlined in Table 5 below.

Table 5: Final Ranking Weighting

Final Ranking Weighting	
Demand	**0.3**
Constructability	**0.7**

Constructability has been given a greater weighting in the final ranking than demand. This is because the ability to build the connecting pipelines is more important than the demand of the cluster, at this stage. Alongside this, as the clusters have been created based upon the top 200 users within the network, the influence of demand has already been incorporated into the process at an earlier stage.

Table 6: Final Weighted Cluster Ranking

Cluster	Final Rank		
	2028	2032	2037
Teesside			
1 Hartlepool	17	18	18
2 Stockton & Billingham	4	4	4
3 Teesmouth	30	30	30
4 Middlesborough - Teesside South	14	13	13
5 Skinningrove	20	21	21
6 Greatham - Hartlepool South	22	17	17
Bishop Auckland to Pannal			
1 Newton Aycliffe & Bishop Auckland	8	7	5
2 Darlington	26	26	26
3 Spennymoor - Bishop Auckland North	7	8	8
4 Bedale - Thrintoft	9	9	9
5 Masham - Thrintoft	19	20	20
6 Ripon	15	16	16
7 Menwith Hill - Harrogate	16	15	15
8 Harrogate	28	27	27
Leeds / Bradford			

Cluster	Final Rank		
	2028	2032	2037
1 Leeds Ring Main	11	12	11
2 Huddersfield - Bradford	2	3	3
3 Bradford	29	29	28
4 Holbeck & Hunslet	23	25	25
5 Stourton - Leeds South	21	22	22
6 Leeds Central	-	-	-
7 Wakefield - Leeds South	18	19	19
8 Pontefract to Huddersfield	-	-	-
Towton to Asselby			
1 Selby	3	2	2
2 Goole	25	23	23
3 Howden	-	-	-
4 Selby & Knottingley	-	-	-
5 Tadcaster Sherburm	24	24	24
6 British Gypsum - Tadcaster Sherburn	5	5	6
7 Knottingley	10	10	10
Humber			
1 Howden	12	11	12
2 West Hull	27	28	29
3 Hull	13	14	14
4 East Riding and Storage	6	6	7
Tyneside			
1 Tyne & Wear	1	1	1

There have been some clusters that have been phased either earlier or later than their rank would suggest, for example, Tyneside cluster 1. These clusters have been phased at different times than expected due to the interdependencies between clusters being completed, e.g. the development of Tyneside being dependent on the network establishment in Teesside. Similarly,

6.3 Results Summary

The dates at which clusters have been selected to be connected to East Coast Hydrogen, along with the corresponding supply and demand to the network, and the length of the pipelines to be developed, are outlined in Table 7.

Table 7: ECH Phasing Summary

Year	Clusters connected	Total Supply (TWh/year)	Total Demand (TWh/year)	Repurposed pipework in phase (km)	New pipework in phase (km)
2028	Teesside clusters 1, 2, 3, 5 Bishop Auckland to Pannal cluster 1 Towton to Asselby clusters 1, 6, 7 Humber clusters 1, 2, 3, 4	19.4	3.7	90.5	185.3
2032	Teesside cluster 4 Bishop Auckland to Pannal clusters 4, 5, 6, 7 Leeds-Bradford clusters 1, 2, 5, 7 Towton to Asselby clusters 2, 5 Tyneside cluster 1	40.8	9.8	117.4	92.8
2037	Teesside cluster 6 Bishop Auckland to Pannal clusters 2, 8 Leeds-Bradford clusters 3, 4	40.8	12.1	30.5	48.4

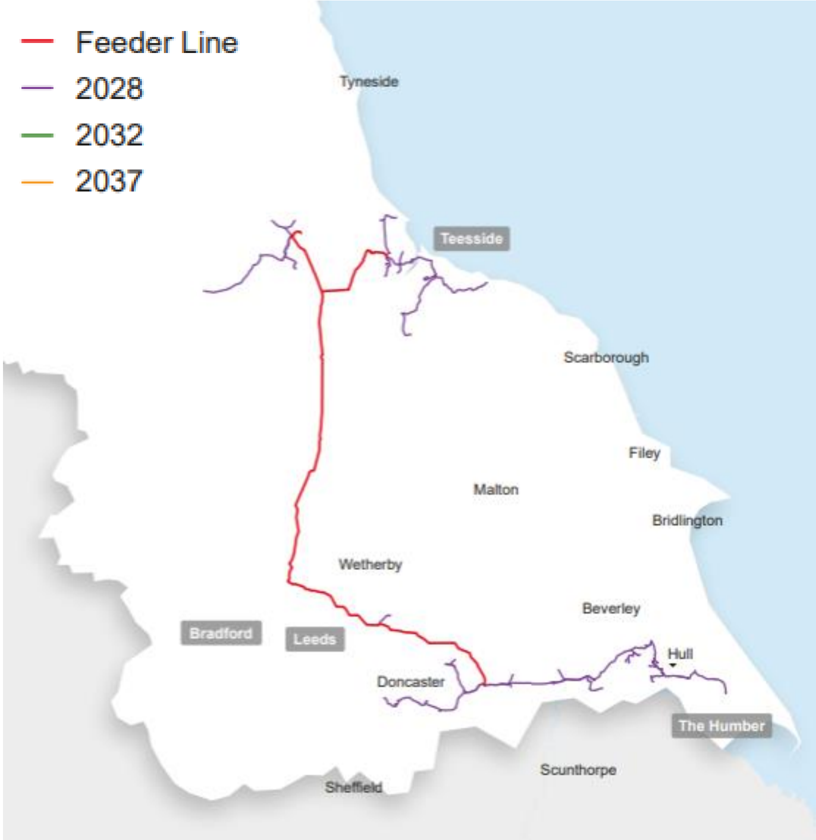


Figure 10: ECH Phasing Plan 2028 Map

The network in 2028, outlined in Figure 10, shows the development from Project Union to form the backbone of the East Coast Hydrogen project. This connects the existing repurposed feeder lines to the key industrial hubs in Teesside and the Humber.

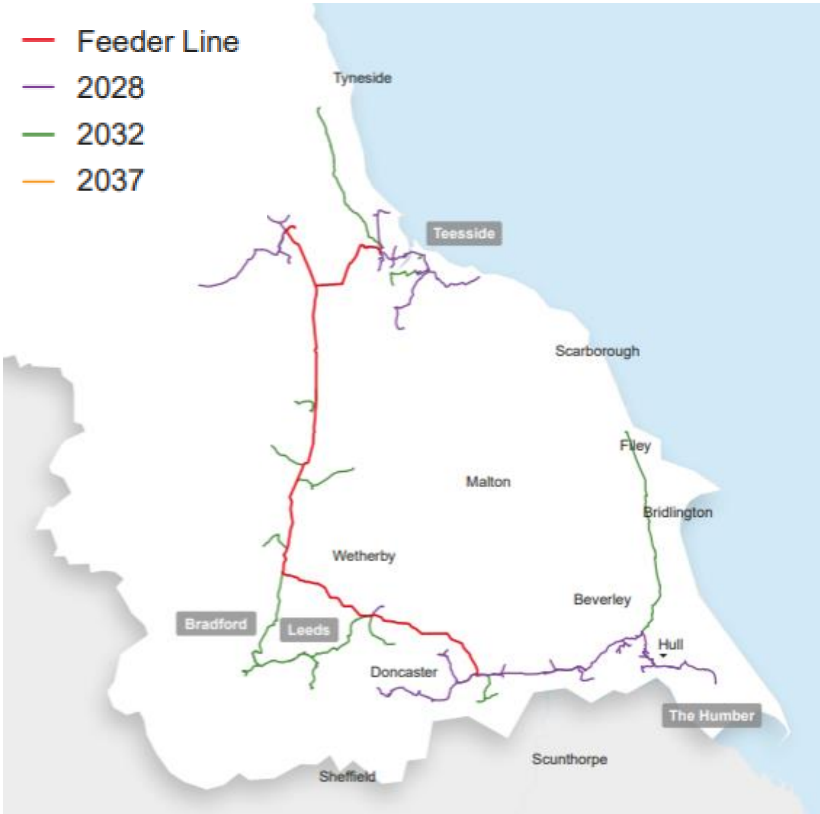


Figure 11: ECH Phasing Plan 2032 Map

The network in 2032, outlined in Figure 11, shows the expansion of the East Coast Hydrogen Network. There shall be development from the Humber up the east coast, the extension of the network from Teesside to Tyneside, and the formation of a ring main connecting Leeds and West Yorkshire. There is also the first branches from the backbone established in 2028, across the region.

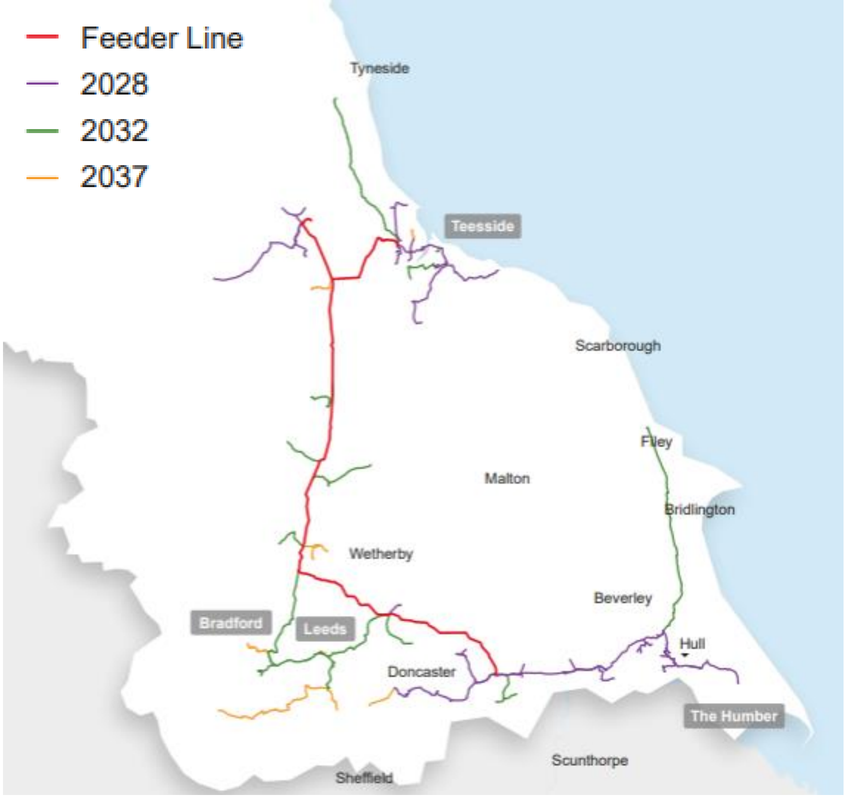


Figure 12: ECH Phasing Plan 2037 Map

In 2037, as shown in Figure 12, the network will have expanded further into both industrial and urban areas, in particular in West Yorkshire.

Figure 13 below provides a full summary graphic of the project phasing.

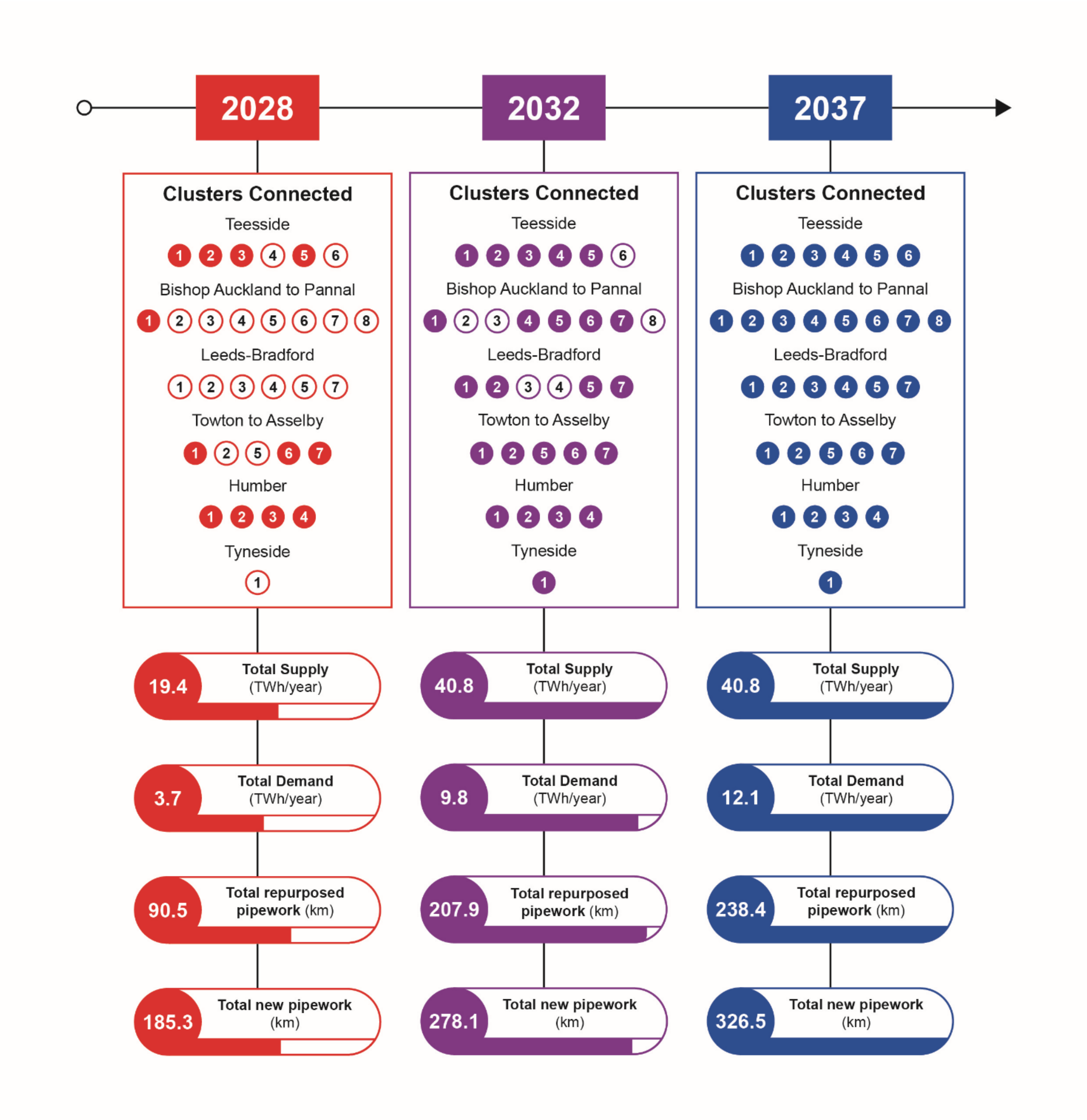


Figure 13: Final Phasing Plan Infographic

6.4 Future Development

In the next stage of the East Coast Hydrogen, the phasing plan will be extended to incorporate the following additional information:

- Expansion of ECH network into wider Northern Gas area, such as Cumbria, Tyneside and the York area.
- Review of users outside of top 250 users to establish additional connections within the proximity of the currently identified users.

The phasing plan will need to be reviewed at the start of Pre-FEED, to update the plan with the most up to date demand and production information and base decisions on the certainty of supply and consumption at the time.

7. Stage 3 - Town Trial(s) Outline Planning Report

7.1 Hydrogen for Heat Scope

NGN and DESNZ have been working on a village trial located in **Redcar**, switching approximately **2,000-meter points** from methane to hydrogen gas as a heat source, the village trial is expected to go live during **2025** and shortly after the UK Government will announce a position on hydrogens role for heat and decarbonisation.

Before the UK Government official announcement due in 2025, DESNZ have invited NGN and other GDNs to submit proposals for converting a town, defined as a minimum **10,000-meter points**, from methane to hydrogen gas, following on from the village trial(s). NGN responded to the proposal invitation detailing potential town options within the three key regions linked to the ECH project: Teesside, West Yorkshire and Hull & Humber.

The town options proposed by NGN each represent approximately **20,000-meter points**. Arup were tasked by NGN to develop the scope for the Town Trial(s) Outline Planning Phase, with a focus on identifying the optimal town section to proceed as a trail within each of the three regions.

The contents of the Town Trial(s) Outline Planning Phase scope report can be seen in Figure 14.

Figure 14: Topics discussed in the Hydrogen for Heat report.

7.2 ECH and Town Trial(s) Interface

During the Town Trial(s) Outline Planning Phase NGN and a third-party consultant will further develop the town sectors within the three regions and shall create several options to determine the optimal initial town to commence the Hydrogen for Heat rollout programme.
The NGN and third-party consultant Town Trial(s) project team will reference the ECH project reports to further develop the town(s) optioneering process, the details include:

- The locations identified for hydrogen production and storage.
- The locations and demand identified for the industrial/commercial users.
- The repurposed and new pipeline networks designed to connect industrial/commercial users to hydrogen supply.
- The pipeline networks connecting production and storage across the three regions.
- Potential connection points between identified town sectors and the ECH pipeline network.
- The ECH identified hydrogen demand and the town hydrogen demand. Determining the potential demand, the producers and suppliers can provide; ensuring there is no conflict in hydrogen supply across the two projects.

It is anticipated that the first town sector to undergo methane to hydrogen gas conversion will reside in the Teesside region due to the village trial location within Redcar and the hydrogen production/storage projects ongoing in the region. The second town sector is likely to reside within the Hull & Humber region due to the ongoing hydrogen production/storage projects in the region, West Yorkshire will follow on once the ECH pipeline connects the Teesside and Hull & Humber regions.
It is expected that the below initial town options will be considered in the Teesside area, as a minimum:

1. Expanding the Redcar village trial from 2,000-meter points to approximately 20,000-meter points.
2. A town sector north of the Tees river close to the Kellas H2NorthEast production site.
3. A town sector south of the Tees river (excluding Redcar) close to one of the several production sites.
4. The town sector closest to the ECH hydrogen pipeline.

8. Stage 3 - Outline Design Pipelines

This section provides guidance on the key considerations for the specification and construction of newbuild hydrogen pipeline assets.

8.1 Overview

The applicable standards for hydrogen pipelines are:

- API, Specifications for Line Pipe. API Specification 5L, 43rd edition, 2004.
- BSI Standards Publication, “Pipeline Systems – Part 1: Steel pipelines on land – Code of practice”, PD 8010-1:2015+A1:2016, November 2016.
- IGEM, “TD1 Steel pipelines for high pressure gas transmission. Supplement 2 – High pressure hydrogen pipelines”, Edition 5.
- IGEM, “TD1 Steel pipelines for high pressure gas transmission.”, Edition 5.
- ASME B31.12, “Hydrogen Piping and Pipelines”, 2019.
- ASME B36.10, “Welded and Seamless Wrought Steel Pipe” 2022 Edition, June 30, 2022.
- IGEM, IGEM/H/1, Reference Standard for low pressure hydrogen utilisation with Amendments June 2022 and June 2023.
- BSI Standards Publication, “Petroleum and natural gas industries. Pipeline transportation systems”, BS EN 14161:2011+A1:2015, June 2015.

There are some design considerations which vary for hydrogen compared to natural gas pipelines, including:

- Pipeline materials – As stated in the Repurposing Strategy report (293805-ARUP-RPS) and the Options and Phasing Study Report (293805-ARUP-OSR), cast iron pipes are not appropriate to transmit hydrogen due to hydrogen embrittlement. Hydrogen above 7 bar can be transported through PE or X70 grade steel or less to reduce the likelihood of hydrogen embrittlement in the pipelines. Due to the risk of hydrogen embrittlement with higher strength steels, the design factors in IGEM/TD/1 increase (i.e., are less conservative) the lower the grade of steel used. For example, X70 has a design factor of 0.37, whereas X52 and below has a design factor of 0.5.
- Velocities – Max velocities in hydrogen pipelines will exceed those in natural gas services. The velocities shall however not exceed the erosion velocity for hydrogen in the pipelines upstream at the pressure reduction installation (PRI). See the Outline Design of Facilities and IGEM TD13.
- Design factor – The design factor used in hydrogen transmission design is limited to 0.5, as opposed to 0.72/0.8 in natural gas systems. Therefore, pipelines will typically have a higher wall thickness compared to natural gas systems. This is due partly to increased risks associated with hydrogen and therefore the requirements in the IGEM TD1 Hydrogen supplement and also to reduce stress in pipes to reduce the risk of hydrogen embrittlement.
- Line sizing – The IGEM TD1 line sizing formulae can be used initially. These formulae may however underestimate the pressure drop and flow rate for hydrogen in pipelines as this will vary compared to that of for natural gas.
- Line spacing – The minimum possible building proximity distance and line spacing guidance is stated in IGEM TD1. The IGEM TD1 Hydrogen Supplement does not mention any hydrogen specific line spacing guidance.

- Wall thickness – The IGEM TD1 Hydrogen Supplement wall thickness formulae should be used to calculate appropriate wall thicknesses of pipework. These calculations should consider the design factors and material performance factors of materials. Proximity distances have a large impact upon pipe wall thickness. However, these are not notably different for hydrogen, since at the minimum proximity distance of 3m, the design factor cannot exceed 0.5, which it is already limited to for hydrogen.

8.2 Reference design

8.2.1 Pipeline

Seamless API 5L X42 Grade B steel is widely available and allows the maximum design factor to be used. The mechanical properties of API 5L X42 Grade B steel line pipe are shown in Table 1.

Table 1: API 5l X42 Grade B steel properties

Grade	Specified Minimum Yield Stress (N/mm^2)	Specified Minimum Tensile Stress (N/mm^2)
L290 or X42	290	415

The reference design is based upon a MOP of 50barg. As the design factor is limited to 0.5, proximity distances are less of a concern and for this reference case, the minimum distance of 3m has been assumed. This means that the nominal wall thickness of the pipeline must be a minimum of 19.1 mm. Considering the requirements, the minimum wall thickness of each pipe size considered in the line sizing exercise was set as the next standard wall thickness up from 19.1 mm accounting for manufacturing and welding tolerances. Given that seamless X42 grade API 5L steel pipe was selected, the manufacturing tolerance is ±0.5 mm, therefore, the minimum nominal wall thickness to ensure heavy walled pipe along the pipeline is 19.6 mm. The nominal pipe sizes selected to be taken forward to line sizing are shown in Table 2.

Table 2: Reference pipeline thicknesses

Nominal bore (inches)	Schedule	Wall thickness (mm)	Internal diameter (mm)
6	XXS	21.95	124.4
8	140	20.62	177.86
10	120	21.44	230.22
12	100	21.44	281.02
16	80	21.44	363.52
18	80	23.83	409.54
20	60	20.62	466.76
24	60	24.61	560.78

8.2.2 Construction methods

The construction methodology for hydrogen pipelines is not considered to be any different to natural gas pipelines. The pipelines which were routed for Pre-FEED stage used combinations of the following installation methodologies:

- Open cut – The open cut method is where open-air trenches are excavated, the pipe is laid, the soil is backfilled and then the surface is restored. This is used for cross country, roads and crossings applications.

- Horizontal directional drilling (HDD) – HDD removes the need for a trench as it creates an arched tunnel in the ground with a steerable drill. First a drilling stem drills a bore hole. The drilling stem contains a drill bit which is then used to create a pilot hole. A reaming tool is then used to enlarge the hole. This method is used for cross country and crossings applications and more suited to softer soils.

- Auger bore – Auger boring is similar to HDD. A horizontal bore is created by jacking a steel casing through the earth. Then a rotating auger is used to remove the earth from the hole. After the hole is created a casing is installed which prevents the hole from collapsing. This casing is then used to install the pipes. This method is used for crossings through various ground conditions including hard rock.

- Micro tunnel – Micro tunnelling is a remote-controlled trenchless method best used for short length crossings in wet and soft earth.

9. Stage 3 - Outline Design Facilities

This section explains the difference between 100% natural gas and 100% hydrogen facilities. It does not consider facilities for natural gas / hydrogen blends.

The standards that are applicable for the outline design of the facilities are the same as those for the pipelines mentioned in Outline Design for Pipelines, and also:

- IGEM TD13 Edition 2 – Pressure regulating installations for Natural Gas, Liquified Petroleum Gas and Liquefied Petroleum Gas/Air, 2011
- IGEM TD13 Supplement 1 – Pressure regulating installations for hydrogen at pressures exceeding 7 bar, 2021
- The Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) 2002
- IGEM/SR/25 Edition 2 Communication 1748 Hazardous area classification of Natural Gas Installations, 2010
- IGEM/SR/25 Edition 2 with amendments 2013 Hydrogen Supplement 1
- Energy Institute Model code of safe practice EI IP-MCSP-P15 S10.1 Onerous Hazardous Area Classification, 2015
- BS EN 60079-10-1 : 2015, concerning the classification of flammable gas or vapour hazards and the selection of equipment to be used in hazardous areas

Some of the design differences for hydrogen above ground installations (AGIs) compared to natural gas AGIs are as follows:

- Hazardous area zones – IGEM SR25 details how to calculate hazardous area zones for natural gas applications and the IGEM SR25 Hydrogen Supplement explains how to calculate hazardous area zones for pure hydrogen. Comparing IGEM SR25 and the IGEM SR25 Hydrogen Supplement shows that the hazardous areas for hydrogen are larger than those for natural gas. This may impact some of the existing AGIs which are to be repurposed for hydrogen use as layouts or existing equipment replaced with ATEX rated equipment. The difference between the hazardous zone distances for outdoor freely ventilated systems for example can be seen in Table 8.

Table 8: Outdoor freely ventilated zoning distances for natural gas and hydrogen vents

Operating pressure (bar)	Zoning distance (X) under normal conditions (m) – Natural gas	Zoning distance (X) under normal conditions (m) - Hydrogen
> 100 ≥ 200	N/A	7.0
> 75 ≥ 100	1.5	5.0
> 50 ≥ 75	1.5	4.5
> 30 ≥ 50	1.0	3.5
> 20 ≥ 30	0.75	3.0
> 10 ≥ 20	NE	2.5
> 7 ≥ 10	NE	2.0
> 5 ≥ 7	NE	1.5
> 2 ≥ 5	NE	1.5
> 0.1 ≥ 2	NE	NE
≥ 0.1	NE	NE

Table 8 shows that for example at > 30 ≥ 50 bar, the zoning distance for natural gas is 1 m but for hydrogen it is 3.5 m.

- Erosion velocity – Pressure reduction installation (PRI) pipework must be sized so as to not allow the hydrogen to exceed its erosional velocity at peak conditions. High velocities increase turbulence in the pipe and increases pressure drops. It also increases sound pressure levels (aerodynamic noise) which can contribute to internal piping erosion and vibration due to acoustics. The erosional velocity formula and calculation method is in the IGEM TD13 Hydrogen Supplement.
- Venting systems – Vent stacks for hydrogen must be higher than those for natural gas due to the additional associated safety risks mentioned in the IGEM TD13 Hydrogen Supplement Section 14.2.3.1. For example, a vent pipe with a flow of 1 kg/s and a nominal diameter of 100 mm has a zoning distance of 2.4 m if it is for natural gas and 8.83 m if it is for hydrogen.
- Valve selection – Hydrogen is more prone to leakage compared to natural gas due to its smaller molecule size. This is a key consideration when selecting valves. Welded connections should be used where possible rather than flanges, and if flanged connections are used appropriate gaskets need to be specified (see IGEM TD13 hydrogen supplement for details). Flange leakage calculations can be undertaken as part of stress analysis. Leakes can also occur around the valve stem. Stem packing can be used to reduce the risk of this type of leak.
- Gas cleaning – All filter unit materials must not contain hydrogen sensitive materials.
- Noise – To attain the same energy flow with hydrogen, the velocities will have to be higher than those used in the natural gas pipelines. Hydrogen has a sonic velocity approximately four times higher than natural gas. Control valves and relief valves are particularly susceptible to sonic vibration related failures as they have sonic or near sonic velocities.
- Metering – As stated in the IGEM TD13 Hydrogen Supplement, all meters should be made of hydrogen compatible materials and recalibrated for hydrogen service.
- Pre-heating –Natural gas cools when the pressure is reduced due to the Joules-Thompson effect. Pre-heaters are therefore required at pressure reduction stations (PRSs). Pre-heating of the hydrogen is not required as it does not experience the Joules-Thompson effect at ambient temperatures.
- Material – Material selection should be carefully considered. See Outline Design for Pipelines for details on hydrogen compatible materials. Some components have elements which are made from soft polymers such as seals or gaskets which are sufficient for natural gas but would allow hydrogen to leak due to its smaller molecule size. In these cases, hardened seals should be used instead.
- Welding – The welding regulations stated in the IGEM TD13 Hydrogen supplement should be followed.
- Hydrogen rated components – All components including gaskets, fittings, instruments, meters, bolts, studs, and washers must be appropriately specified and certified for use with hydrogen. All components should have minimal compression fittings to reduce the risk of leaks.

Additional good practice:

- Allow space for growth on the hydrogen AGIs as demand for hydrogen will likely continue to increase and this would future proof the assets.
- As stated in the IGEM TD13 Hydrogen Supplement, if AGIs are to be operated with both hydrogen and natural gas, clear signage and demarcation must operate to show designated hydrogen areas and natural gas areas.

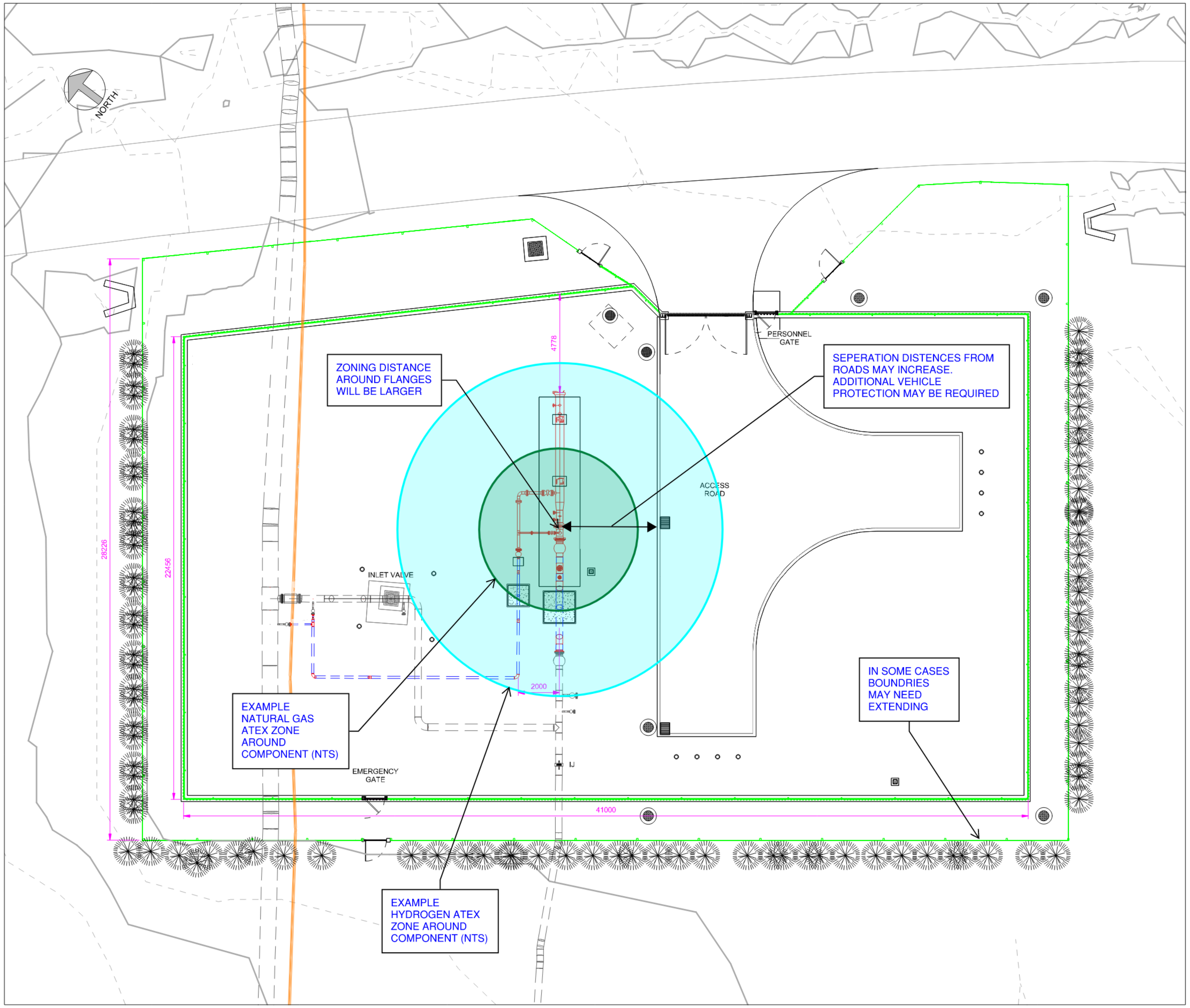
A summary of the design considerations for building new hydrogen AGIs, for retrofitting natural gas AGIs for hydrogen, and for retrofitting part of a natural gas AGI for hydrogen while part of the site remains for natural gas use is shown in Table 9.

Table 9: Design considerations summary

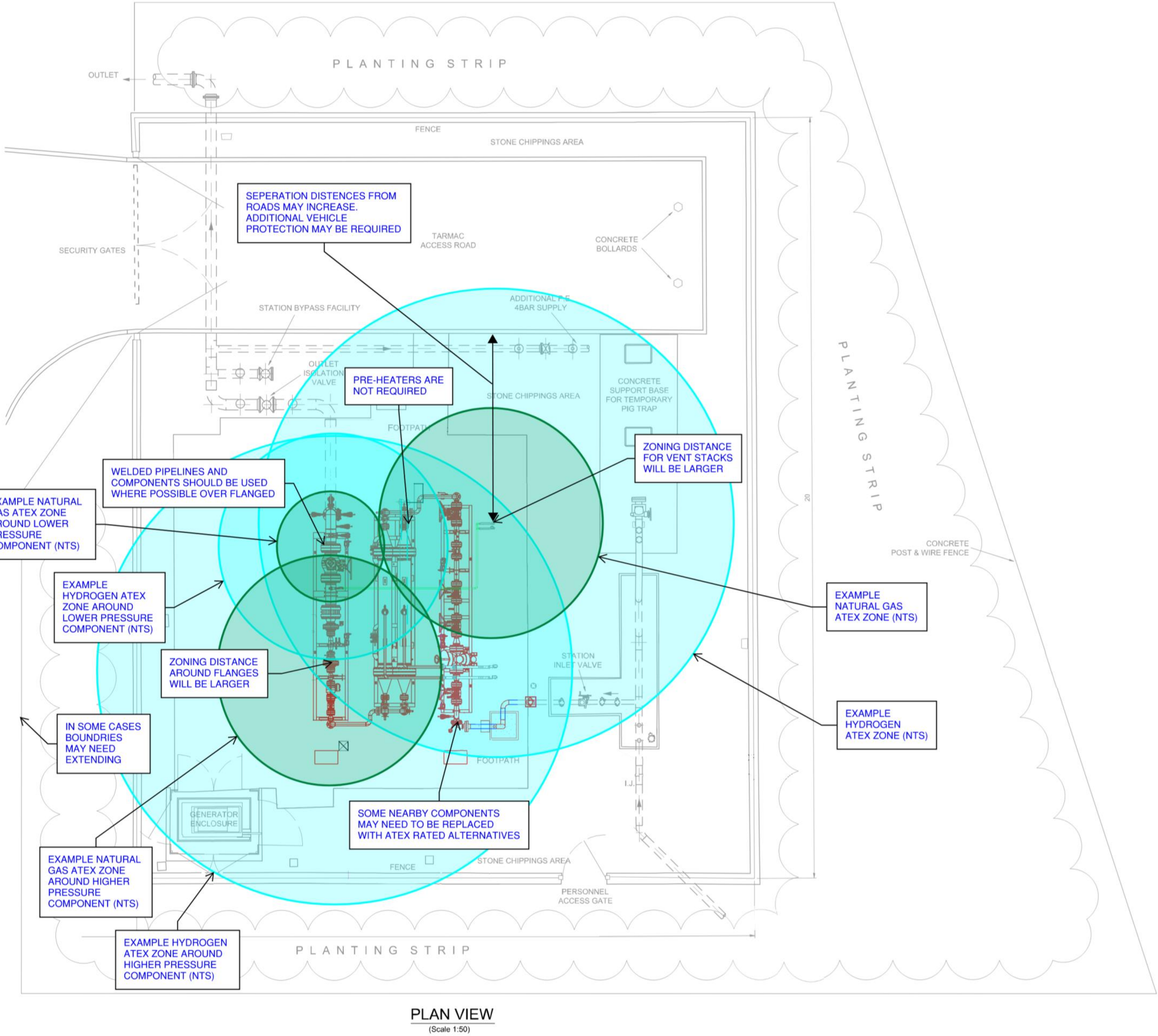
	Newly built for hydrogen use only	Retrofitted for hydrogen use only	Partially retrofitted for hydrogen use partially maintained for natural gas use
Hazardous areas and layout	Hydrogen ATEX zones are larger than those for natural gas. Layouts and equipment must comply with IGEM SR25 Hydrogen Supplement.	Hydrogen ATEX zones are larger than those for natural gas. Layouts and equipment must comply with IGEM SR25 Hydrogen Supplement. Layouts and site boundaries may have to change, equipment which is now within the zones must be replaced with ATEX rated alternatives.	Hydrogen ATEX zones are larger than those for natural gas. Layouts and equipment must comply with IGEM SR25 Hydrogen Supplement. Layouts and site boundaries may have to change, equipment which is now within the zones must be replaced with ATEX rated alternatives.
Erosional velocity	N/A.	Energy capacity may be reduced due to a limitation on velocity.	Energy capacity may be reduced due to a limitation on velocity.
Venting systems	N/A.	Vent height may need to be increased to maintain sufficient separation from hazardous area zones.	Vent height may need to be increased to maintain sufficient separation from hazardous area zones.
Valve selection	All valves must be specified in accordance with relative standards such as the IGEM TD13 Hydrogen Supplement.	Valves assessed against relevant standards. Any natural gas valves that remain will require replacement of gasket, seals and stem packing as a minimum.	Valves assessed against relevant standards. Any natural gas valves that remain will require replacement of gasket, seals and stem packing as a minimum.
Filters	N/A.	Filter materials and pressure drop need to be assessed for compatibility.	Filter materials and pressure drop need to be assessed for compatibility.
Pre-heating	Not required.	Decommission and remove any pre-heaters.	Decommission and remove any pre-heaters in the hydrogen areas of the site.
Material selection	All equipment must be hydrogen compatible. Follow the IGEM TD1 Hydrogen Supplement.	All equipment that is made of hydrogen compatible materials can be retained subject to condition surveys. All non-hydrogen compatible equipment must be replaced.	All equipment that is made of hydrogen compatible materials can be retained subject to condition surveys. All non-hydrogen compatible equipment must be replaced.
Piping	Specified in accordance with ASME B31.12 or equivalent.	All piping that is made of hydrogen compatible materials can be retained subject to condition surveys. All non-hydrogen compatible equipment must be replaced.	All piping that is made of hydrogen compatible materials can be retained subject to condition surveys. All non-hydrogen compatible equipment must be replaced.
Other components	All components must comply with applicable standards such as the IGEM TD1 and TD13 Hydrogen Supplements.	All components must comply with applicable standards such as the IGEM TD1 and TD13 Hydrogen Supplements.	All components that are used with hydrogen must comply with applicable standards such as the IGEM TD1 and TD13 Hydrogen Supplements.

Example natural gas AGIs are shown below in Drawing 1and Drawing 2. These drawings highlight what will have to be different on the sites if they are to be repurposed for hydrogen use. The drawings include a pig launch site and a pressure reduction installation.

Drawing 1: Example natural gas pig launch station. Typical areas which will change for hydrogen repurposing have been highlighted



Drawing 2: Example natural gas pressure reduction installation. Typical areas which will change for hydrogen repurposing have been highlighted



10. Stage 3 - Project Capital Cost

An indicative project Capital Expenditure (CAPEX) was estimated in a dedicated spreadsheet for the final selected routes. The estimated CAPEX consists of direct costs, indirect costs and contingency. The CAPEX calculations can be seen in Appendix A.

10.1 Direct Costs

Direct costs cover the procurement, fabrication and installation costs of pipelines and associated AGIs, including the costs of repurposing or modifying existing facilities.

10.1.1 New Pipelines

The cost of new pipelines was estimated using the model on the Optioneer™ platform. The platform applies different construction methods to each section of a route, dependent on the terrain or features it is running through and the complexity of these. Construction methods include cross country, linear feature crossing or linear feature following. As well as the general construction methods, specific crossing technologies such as Horizontal Directional Drilling (HDD) are selected at each crossing and the relevant costing applied. This information is used along with the size and length of pipe in the segment to estimate the material and construction costs associated with each pipeline. Costs were assigned to each construction methodology in terms of fixed costs (for start-up, equipment etc.) and linear costs (for labour, materials etc) which enabled the buildup of CAPEX for each pipeline. The model was populated with capex inputs from multiple sources including NGN costing models, previous installation quotations and historic costings.

10.1.2 Repurposed Pipelines

Pipeline repurposing cost is estimated by taking 30% of the cost an equivalent new pipeline as estimated in the Optioneer model. This factor is assumed to cover allowance for:

- New natural gas assets needed to facilitate repurposing.
- Investigations and condition assessments.
- Refurbishment of sections where required.
- Replacement of any block valves.
- Any other costs associated with safety / environmental permits.

10.1.3 AGIs

A bottom-up approach is used to estimate the cost of each AGI based on AGI type (offtake / PRI / pig trap site) and status (new / extended / modified), while taking into account the number and size of incoming / outgoing lines and their pigging requirements. The cost build-up is done within the CAPEX spreadsheet using NGN norms (where available) supplemented by norms derived from Aspen Capital Cost Estimator software.

The total cost of each AGI is calculated by adding the following components:

- Land purchase
- Civils
- Fencing
- Pipework, valves and fittings

- Pig traps (for HP and IP lines only)
- Electricals and instrumentation
- Metering (for connections to / from the NTS)

Further details on how each of the above components is estimated is provided in Appendix A.

10.2 Indirect Costs

Indirect costs are estimated by applying suitable percentage factors to the total direct cost to cover the costs associated with the following items:

- Engineering (FEED and detailed design): 8%
- Project management: 10%
- Commissioning: 2%

10.3 Contingency

A 20% contingency is applied to the total cost (direct + indirect) in line with the contingency typically included for high risk level projects within NGN.

11. Stage 4 – FEED scope

Part of the Pre-FEED scope, was the scoping and definition of the FEED scope of works. This is detailed in the FEED scope report (293805-ARUP-FEED). The purpose, aims and objectives of the FEED study are detailed below.

Purpose

The Government has set to deliver a decarbonised power sector by 2035 and net zero emissions by 2050. NGN owns 36,000 km of natural gas distribution pipework, and therefore is at risk of a significant reduction in the business and the value of its assets. NGN wish to show the feasibility of much of their assets being transitioned to a hydrogen for energy distribution system with the hope of contributing to meeting the Government's Net Zero Strategy.

Aim

The aim of the FEED stage of the ECH project is to develop a project with the level of detail and cost certainty which would allow it to form the basis of an investment decision under the transport and storage business model.

demonstrate to DESNZ a solution to enable widespread industrial and commercial decarbonisation through development of a hydrogen distribution network, utilising as much repurposed infrastructure as possible.

Goals

The goals of the FEED stage and concurrent Pre-FEED are:

- To develop a feasible network connecting supply, demand and storage
- To enable the decarbonisation of multiple hard to abate sectors
- Support the UK government in achieving low carbon hydrogen and net zero targets
- Provide system resilience and flexibility to the UK energy system
- To catalyse wider system benefits
- Inform final investment decision and a methodology to deliver the project
- Optimise the Return on Investment (ROI) by further optimising the network
- Improve safety outcomes
- Enable application to the anticipated Transport and Storage Infrastructure allocation round.
- Ensure the solution enables the proposed is coordinated of Project Union and development of third-party pipelines.

As part of the FEED study, it is proposed that a Pre-FEED study is undertaken on the remaining NGN areas which were not included in this Pre-FEED study. By this time there should be greater certainty on the Project Union Routing within those areas which will enable the network development to be undertaken.

To achieve the most efficient and viable delivery of the FEED stage, the project scope has been divided as can be seen in Figure 15. This has been designed to balance delivery timescales and the project risks. The network development will begin with specific parts of the HP/IP package to enable Project Union as well as the MP package. This will allow further collation and confirmation of information from stakeholders at the production and consumption ends of the network. The HP/IP package will start later once the connection points from the NGT network, and the MP network have reached a greater level of certainty. The consenting and environmental package will begin at the start of the programme due to the large timescales required and the low risk works which can be undertaken at that stage. The stage 5 Pre-FEED works have minor dependencies from the other packages, but that programme is not as programme critical to the project.

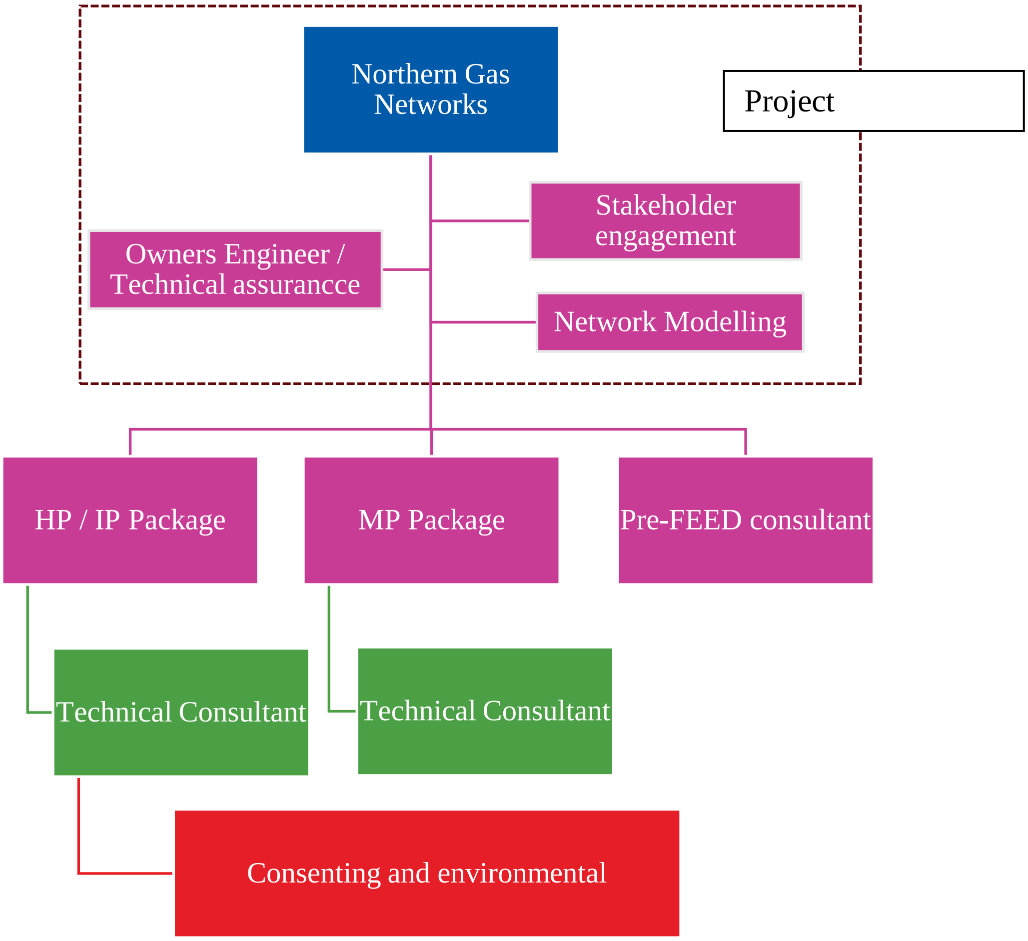


Figure 15: FEED delivery organogram

Appendix A

CAPEX Calculations

REDACTED