NEY NET ZERO HUB - HYDROGEN ROADMAP

Issue 1 – March 2025

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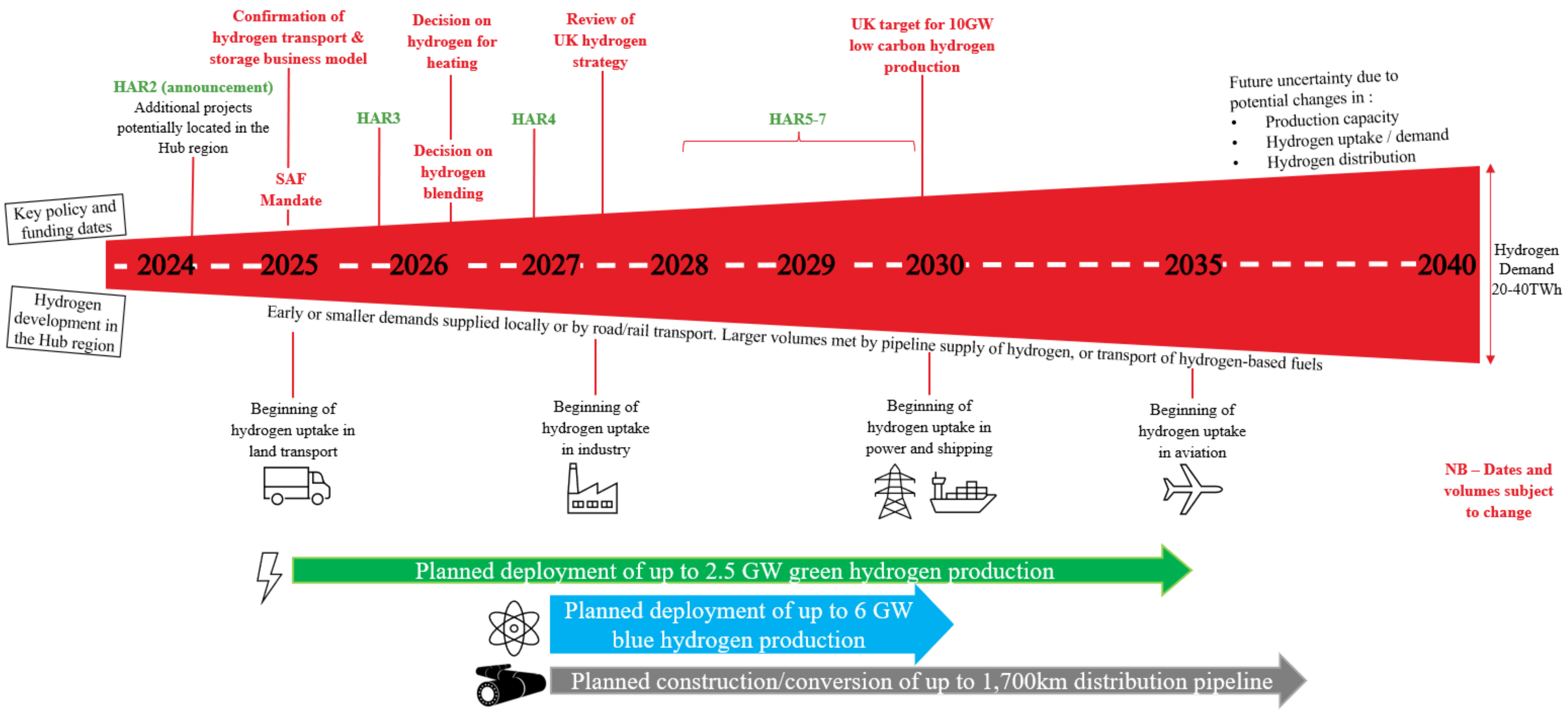
This study has assessed the future production, distribution and use of hydrogen in the North East and Yorkshire Net Zero Hub region, which has exciting potential and will likely contribute significantly to the UK's low carbon hydrogen targets, abating significant emissions and driving investment in the region.

A digital model of hydrogen production, distribution and demand was created and several future scenarios for hydrogen development in the region were assessed.

The tabs at the top of the page show summarised results from each scenario in 2040, with further detail available in the report.

The image shows the summarised roadmap of hydrogen development in the NEY Hub region. Whilst there is some future uncertainty, hydrogen is expected to play a significant role in several key sectors in the region.



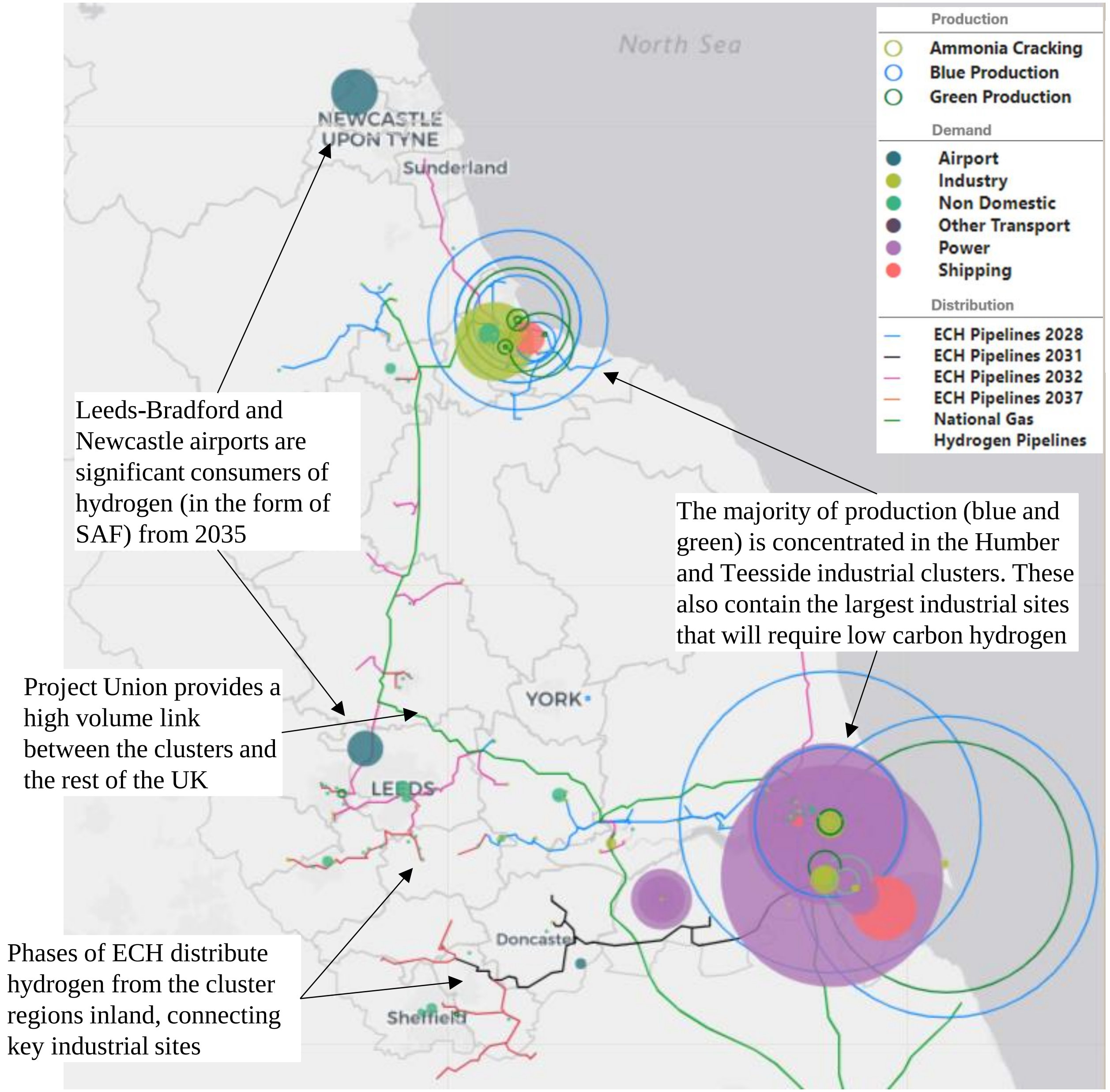
NEY Hub Hydrogen Roadmap | **Scenario 1 Planned projects** | Scenario 2 Reduced hydrogen production | Scenario 3 Reduced hydrogen demand | Scenario 4 Reduced distribution network

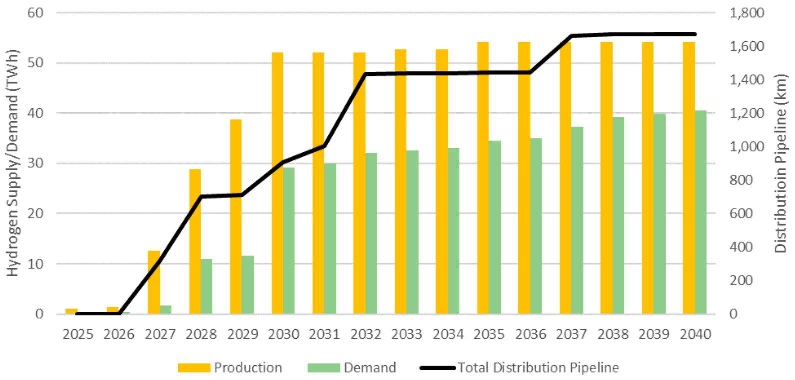
Scenario 1: Planned Projects

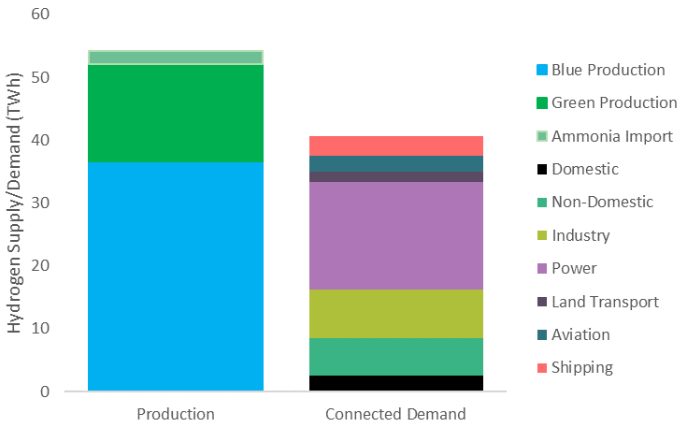
In this scenario, hydrogen production and distribution projects are assumed to be deployed based on their publicised plans.

This is considered an optimistic scenario (ahead of projects obtaining a FID), significant production capacity is planned and the ECH network allows most potential consumers to be connected. Potential locations for additional green hydrogen production sites are indicated.

Production is expected to exceed demand (see opposite) – the NEY region is favourable for production and any 'excess' can be exported via Project Union or as hydrogen-based fuels.







Up to 70MW of local green hydrogen production required

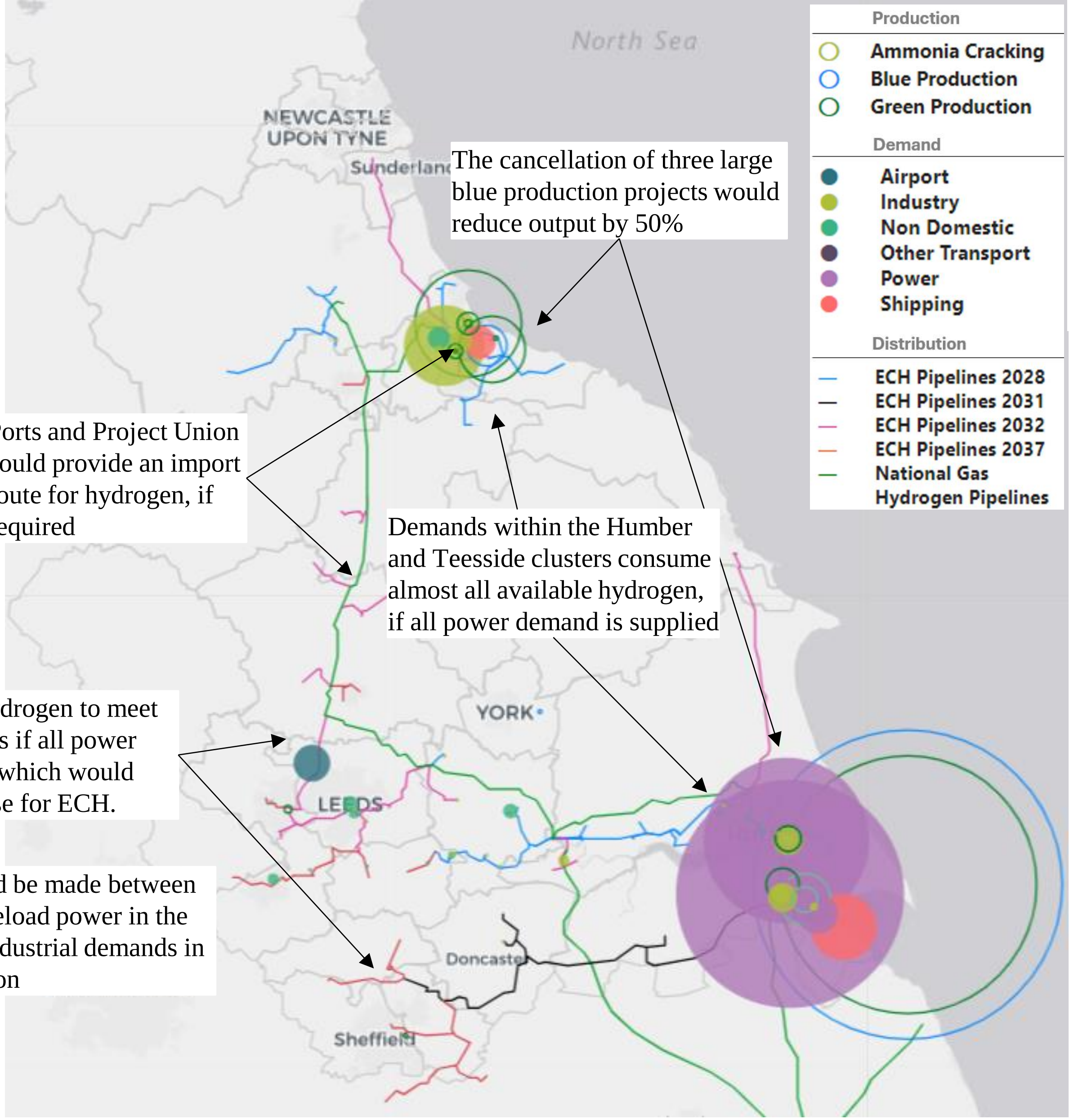
£15bn investment required

Up to 40,000 jobs supported during construction

Scenario 2: Reduced Production

In this scenario, a reduced hydrogen production capacity is modelled. This could occur due to issues or delays in the significant planned scale up of blue or green hydrogen production.

Investment is reduced in this scenario, due to the significant capital cost of large-scale hydrogen production.



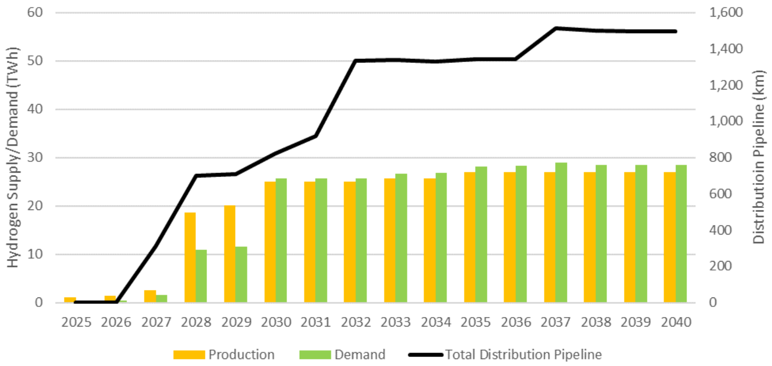
The cancellation of three large blue production projects would reduce output by 50%

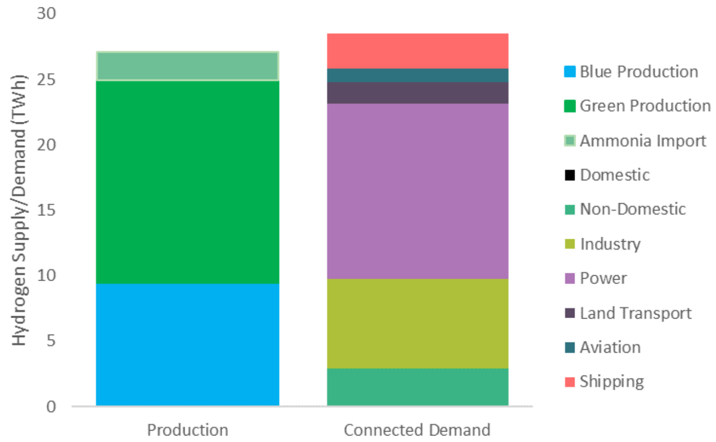
Ports and Project Union could provide an import route for hydrogen, if required

Demands within the Humber and Teesside clusters consume almost all available hydrogen, if all power demand is supplied

There is insufficient hydrogen to meet wider regional demands if all power demands are supplied, which would impact the business case for ECH.

A choice could be made between supplying baseload power in the clusters and industrial demands in the wider region





Up to 70MW of local green hydrogen production required

£10bn investment required

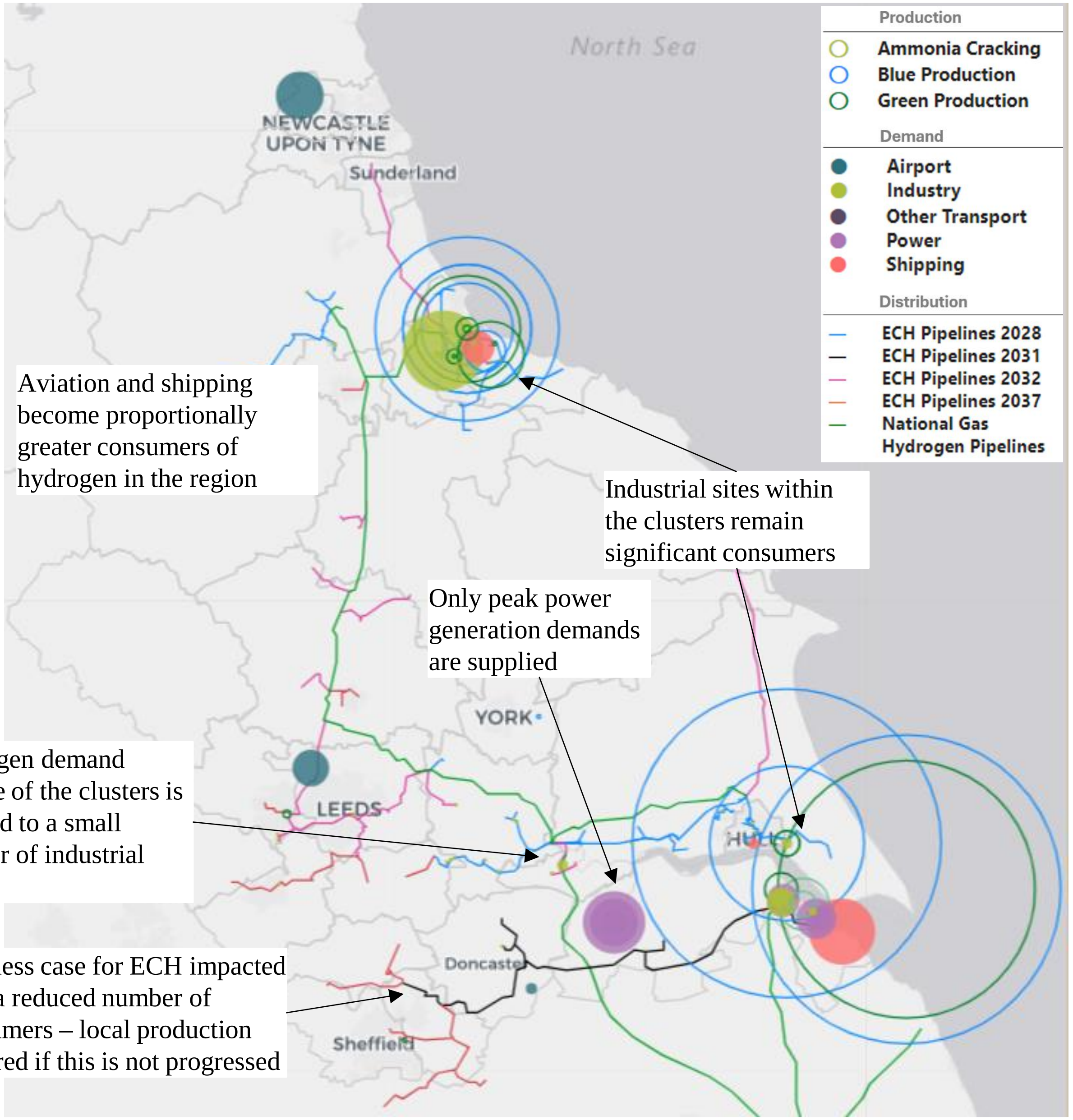
Up to 28,000 jobs supported during construction

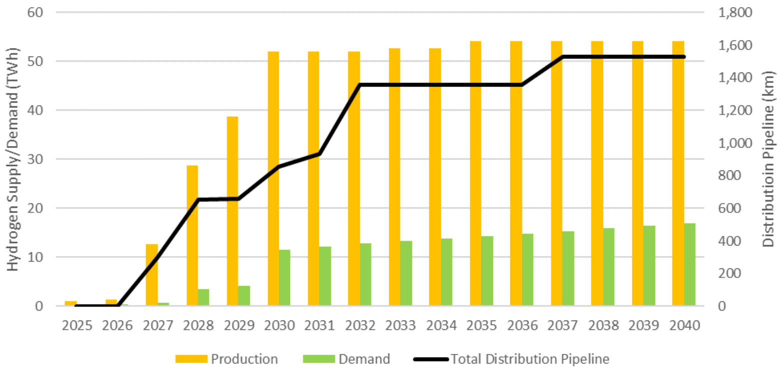
NEY Hub Hydrogen Roadmap | Scenario 1 Planned projects | Scenario 2 Reduced hydrogen production | **Scenario 3 Reduced hydrogen demand** | Scenario 4 Reduced distribution network

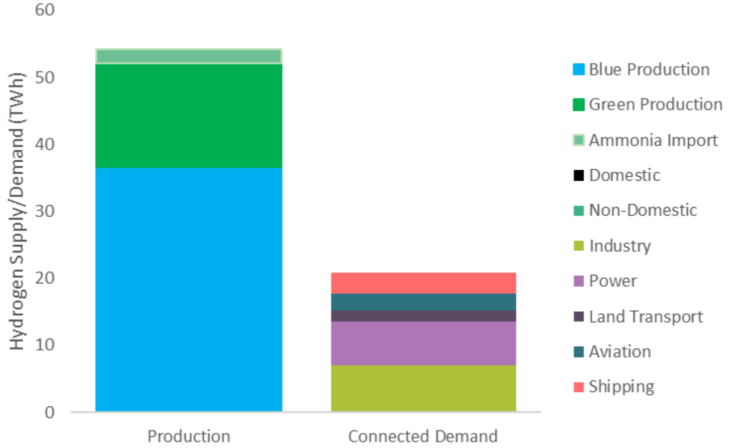
Scenario 3: Reduced Demand

In this scenario a reduced demand for hydrogen was modelled, where it is only used in sectors that have few viable alternatives.

Hydrogen demand across the NEY region is significantly reduced and with no change in production projects, there would be a more significant excess to be exported. This may also reduce the production projects that could be taken forward and impact the business case for ECH.







70-250MW of local green hydrogen production required

£13bn investment required

Up to 35,000 jobs supported during construction

EXECUTIVE SUMMARY

This report contains the findings of a hydrogen roadmap study carried out by Arup for the North East & Yorkshire (NEY) Net Zero Hub. This roadmap study aims to improve the understanding of how hydrogen may be deployed across the whole Hub region. It brings together local plans and strategies into a regional supply/demand context, identifies complementary points and opportunities for collaboration between projects or areas, and highlights the investment/funding requirements to improve the overall delivery of hydrogen projects and assist with the net zero transition. The study is based on data and analysis of planned projects, policies etc. as of September 2024.

The Hub region, in terms of the development of hydrogen as part of achieving net zero targets, has more potential than most. This is a result of the plans for significant hydrogen production facilities in the Humber and Teesside clusters, the high concentration of industry for which hydrogen is a credible pathway for decarbonisation and the presence of other sectors such as power, road transport, shipping and aviation where hydrogen has a potentially significant role to play.

Whilst a number of other studies have been carried out across specific parts of the region, or for specific sectors, this roadmap takes a holistic view of the whole Hub region, investigating the expected future development of hydrogen, and identifying the possible synergies and opportunities available. A digital, geospatial and temporal model of planned hydrogen assets and demand sites was created which allowed the evolution of production, distribution, storage and demand to be simulated, explored, and assessed.

Stakeholder engagement, alongside a comprehensive literature review, provided the evidence and basis for the assumptions used in the model. The model uses independent and impartial data where possible to provide a balanced view of hydrogen's role, working alongside other pathways, in decarbonising different sectors. The modelling of future hydrogen supply/demand is inherently uncertain, but doing so provides a view of the key dependencies and high level findings for the region.

Starting with the latest known plans for asset deployment and best estimates of hydrogen uptake, other scenarios then assessed potential changes in key factors that could affect hydrogen development in the region. These show the wide range of feasible hydrogen supply and demand volumes and are reflective of the current uncertainty surrounding the technology, funding, and relative (when compared with alternative fuels/technologies) advantages in certain use-cases.

If all planned projects are assumed to go ahead, the modelling shows that:

- Total annual hydrogen demand across the region is expected to reach 41 TWh by 2040; with industry and power the largest demand sectors for pure hydrogen and significant demand for hydrogen-based fuels associated with airports and ports.
- 8.5 GW of production capacity is expected to be operational, of which the majority is blue hydrogen. Total planned hydrogen production in the area will reach 54 TWh

- Hydrogen will be distributed between the Humber and Teesside industrial clusters and the UK via the Project Union network. The East Coast Hydrogen (ECH) network will extend from Project Union in phases and allow most hydrogen demands in the wider Hub region to be supplied
- Construction of the planned assets and conversion/retrofit of existing sites is expected to require the investment of approximately £14 billion between 2024 and 2040, potentially supporting up to 40,000 jobs during the period of peak construction.
- Ongoing operation and maintenance of the large hydrogen assets will support longer term roles in the region and the development of hydrogen in the region will require a skilled workforce, bringing significant opportunities for research and innovation that can take place in the Hub region.

The development of hydrogen in the Hub region is, however, dependent on a small number of specific projects or sectors. The impact of changes in these areas was assessed across the different scenarios, showing that:

- A significant proportion of hydrogen supply in the region is dependent on large-scale blue hydrogen production from a small number of announced projects. Issues or delays with these projects would constrain supply in the region and would potentially require prioritisation of sectors and connections.
- If hydrogen uptake is lower in some sectors (e.g. due to high costs or use of alternative decarbonisation pathways), expected demand in the region could be reduced by up to 50%. Two power stations in the Humber region account for a significant proportion of this, but the overall reduction across the region could impact the business case for ECH and some of the planned production projects.
- Without ECH approximately 15% of expected hydrogen demand in the wider Hub region would not be supplied. Depending on funding and site constraints, smaller scale green hydrogen production plants could be utilised to supply key sites and surrounding demands in this case.

Other common factors and dependencies for hydrogen development were identified from the assessment:

- Most planned production projects are expected to be operational between 2027 and 2030, implying an intense period of construction and commissioning. This activity is concentrated in the Humber and Teesside clusters, with some smaller scale production plants located elsewhere in the Hub region.
- There are currently limited plans for development of assets after 2032. Some delays to existing projects may occur and additional projects are expected, given favourable conditions in the Hub region and further government funding rounds.
- In most scenarios, there is significant surplus production capacity planned compared to expected demands within the Hub region. This may lead to a scaling back of planned production, although there are also multiple routes for export of excess production in the region, via Project Union and ports as pure hydrogen or hydrogen-based fuels. Availability of hydrogen could also stimulate further demand in the region from existing or new businesses.

- Not all potential hydrogen consumers are expected to be able to economically connect to a hydrogen pipeline network (based on planned and organic growth). Locations for additional green hydrogen production have been identified for each scenario which could supply sites with few alternatives to hydrogen.
- Hydrogen storage in the Hub region (and more widely) will be crucial. Planned projects include salt caverns and the Rough storage facility which will be required for year-round capacity and to meet the high peak demands of power stations in the region.
- There is sufficient hydrogen production to meet the expected regional demand from aviation and shipping for hydrogen-based fuels. Fuel production capacity was not assessed in this study but could be co-located with demand, in the industrial clusters or other favourable locations.
- Hydrogen development is expected to take place in all parts of the Hub region although with differing focusses. Hydrogen production, large industry demand as well as power generation is concentrated in the Teesside and Humber clusters. Some smaller scale production is planned for inland parts of the Hub region, but a greater focus is on the hydrogen distribution network and supply smaller, dispersed industrial sites as well as urban areas and the two large airports. Further work is required to identify where hydrogen is likely to be required in small industry across the region.
- The private sector is expected to provide most of the required investment in the region, but with government support crucial to underpin business cases through the Hydrogen Production Business Model and the Hydrogen Transport and Storage Business Model. Some projects in the region have already been successful in funding rounds for capital or revenue support, which also assist offtakers in accessing hydrogen at a reasonable cost. Significant investment is also required across sites to enable the switch to hydrogen, with government funding available in some sectors.
- Hydrogen will play a key part in the net zero transition in the region, displacing around 7.5 million tonnes CO_2 if all planned projects go ahead, particularly in harder to decarbonise sectors such as industry, aviation and shipping. The growth in supply of other low carbon energy vectors and technologies (such as electrification) brings additional opportunities, challenges and infrastructure requirements to the Hub region.

To take forward the findings from this study and support the future development of hydrogen in the Hub region, an initial action plan has been produced. This highlights areas in which the NEY Hub can provide coordination and leadership across the constituent members and the region, further develop evidence and test scenarios, and indicate where they can directly support some projects. This action plan is intended to help prioritise short-, medium- and longer-term actions, focusing attention on the most critical areas across the hydrogen supply chain to ensure net zero targets can be reached and relevant stakeholders supported. A hydrogen Working Group is expected to be established which will develop and take forward the action plan.

1 INTRODUCTION

This report describes the methodology and findings of a study to produce a hydrogen roadmap for the North East & Yorkshire (NEY) region. This study was commissioned and funded by the NEY Net Zero Hub (referred to as 'the NEY Hub' hereafter), itself funded by the Department for Energy Security and Net Zero (DESNZ). The study is based on data and analysis of planned projects, policies etc. as of September 2024.

This section introduces the study's aims, scope and approach. Section 2 shows how information and data for the work was gathered, and Section 3 provides a high-level overview of the hydrogen model and methodology. Section 4 presents the results, with the results summary and roadmap shown in Section 5. Further commentary on skills and innovation is provided in Section 6, and the proposed action plan for the NEY Hub is discussed in Section 7.

As part of the same project, a deep dive study into the deployment of hydrogen within the West Yorkshire Combined Authority (WYCA) area was undertaken and reported separately.

1.1 NEY Net Zero Hub - Context

The NEY Hub is a collaboration between five Mayoral Combined Authorities and a Business Growth and Skills Hub. Its aim is to accelerate the transition to net zero in the North East, and to support the UK government's target of reaching net zero by 2050. The NEY Hub works with public sector organisations and their stakeholders and communities, to develop fundable net zero projects and deliver local energy strategy, helping to accelerate the region's ambitious efforts to drive a low carbon, clean growth future.

The Hub's stated aims are to:

- Attract commercial investment into projects and help to develop investment models which accelerate progress to net zero
- Increase the number, quality, and scale of local Net Zero projects being delivered across the region
- Develop and support Net Zero elements to wider programmes and initiatives delivered across England
- Support a national knowledge transfer programme to improve information sharing, training, and evaluation
- Raise local awareness of opportunities for and benefits of local Net Zero investment

The NEY Hub is one of five in England. The Hub region (see Figure 1) contains the Humber[1] and Teesside industrial clusters, large cities such as Newcastle, Leeds, York and Sheffield, as well as a large number of dispersed communities and rural areas.

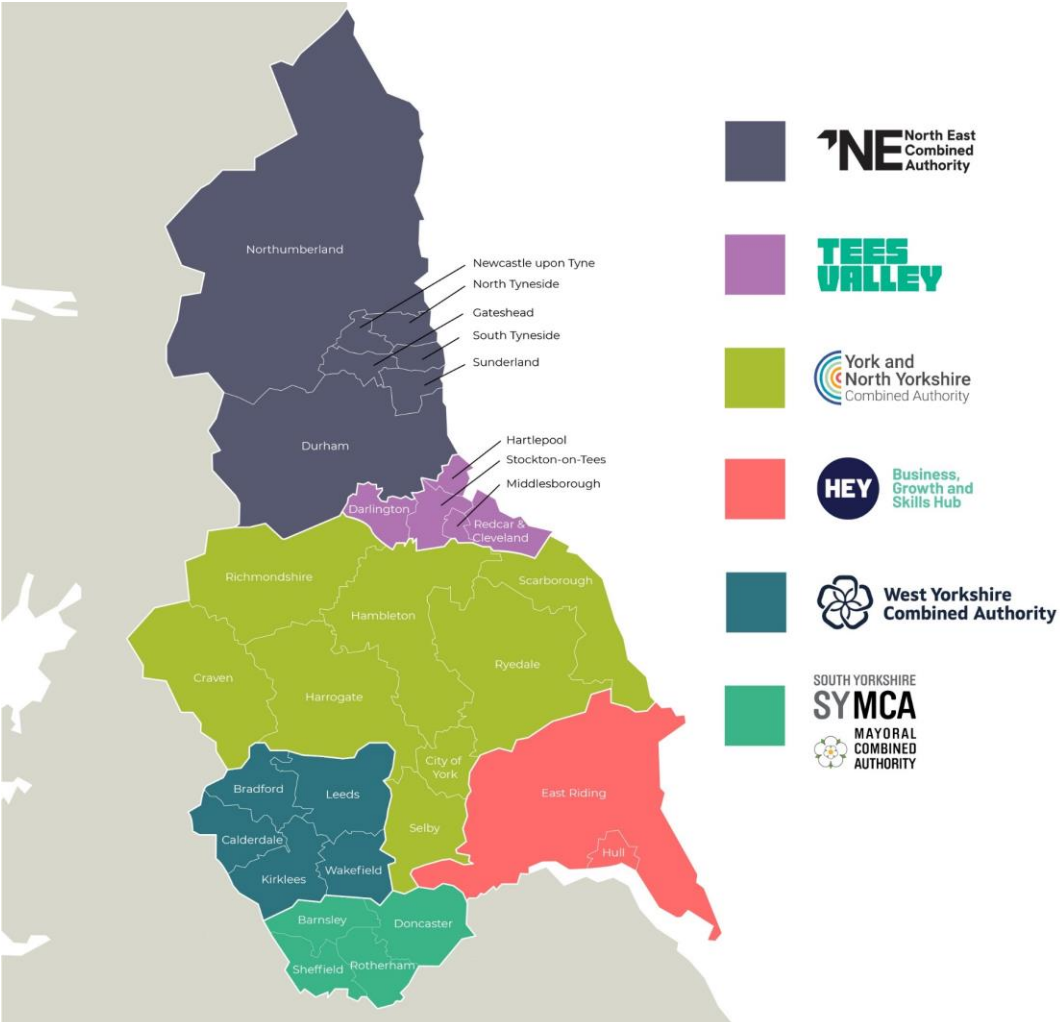


Figure 1 - NEY Hub Region

1.2 Hydrogen – Context

In order to reach net zero by 2050, the UK must largely eliminate the use of fossil fuels across the economy. Hydrogen is one of several low/zero carbon energy vectors that could be used to replace fossil fuels, particularly in sectors such as industry, transport and power. It is generally expected to play a significant role in all of the pathways to net zero for the UK (such as assessed by the CCC[2]).

Currently the UK consumes an estimated 400,000 tonnes of hydrogen each year, predominantly in refining, fertiliser and chemical industries[3]. The vast majority is termed 'grey' hydrogen, produced from natural gas with significant CO_2 emissions. To play a role

[1] The Humber cluster sits across the boundary of the NEY and Midlands Net Zero Hubs – the whole cluster, i.e. including the south bank of the Humber, is considered for this study.
[2] The Sixth Carbon Budget – The UK's path to Net Zero, CCC, December 2020, Link
[3] 2021 Hydrogen Supply and Demand, FCHO, September 2021, Link

in the decarbonisation of these existing sectors and others, hydrogen production will need to be scaled up significantly and produced with low or zero emissions. The CCC 'balanced' pathway estimates that, to do this, approximately 230 TWh or 6,000,000 tonnes per year will be required by 2050.

The UK government is supporting the development and rollout of low carbon hydrogen. One example of this is the UK hydrogen strategy[4], which was published in 2021 and updated in 2023. This strategy lays out the approach, the roadmap, and the targets required to scale up hydrogen production and develop a thriving low carbon hydrogen sector. Key targets are to achieve 2 GW of low carbon hydrogen production by 2025, and 10 GW by 2030, as detailed in the British energy security strategy[5].

A hydrogen sector development action plan[6] highlighted the nature and scale of opportunities across the hydrogen economy in the UK, and the government has since published the hydrogen investor roadmap[7]. This roadmap details key support mechanisms, such as the hydrogen transport and storage business model, the Net Zero Hydrogen Fund (NZHF), and the Hydrogen Allocation Rounds (HAR).

1.3 Project Aims & Scope

1.3.1 Aim

Local and regional governments in the UK have a crucial role to play in the uptake and deployment of hydrogen, and other low carbon technologies, as part of achieving their net zero targets. The deployment of hydrogen assets, and the switch to hydrogen in some sectors, also offers opportunities for new jobs and green growth, supporting local economies and people in the net zero transition.

To date, there has not been a clear analysis of the overall hydrogen asset map and capability across the NEY Hub geography. Whilst there are several substantial projects and initiatives planned in some parts of the region (which have been the subject of separate studies, see Section 2), in other areas there is less certainty on the future availability of hydrogen, and how different sectors can plan to decarbonise.

This roadmap study is therefore an opportunity to improve the understanding of how hydrogen may be deployed across the whole Hub region. It brings together local plans and strategies into a regional supply/demand context, identifies complementary points and opportunities for collaboration between projects or areas, and highlights the investment/funding requirements to improve the overall delivery of hydrogen projects, and assist with the net zero transition.

[4] UK Hydrogen Strategy, August 2021, Link
[5] British energy security strategy, April 2022, Link
[6] Hydrogen sector development action plan, July 2022, Link
[7] Hydrogen net zero investment roadmap, February 2024, Link

Whilst this study can improve the understanding of hydrogen deployment in the Hub region, there remains considerable uncertainty in the sector generally (see Section 1.4.1), and so it cannot provide a definitive view of future outcomes.

1.3.2 Scope

An explicit element of the scope for this study was to provide an impartial and evidence-based view of hydrogen's role in decarbonisation, considering alternative technologies and using independent data where possible. Hydrogen is likely to form some part of the mix of technologies/pathways required to reach net zero across the range of sectors in the Hub region, but this study does not start with a preference or expectation for hydrogen. The following sectors were considered where hydrogen could potentially play a role in reaching net zero, meeting some, all, or none of projected future demand:

- Domestic space heating and domestic hot water (DHW), including supply from district heat networks
- Non-domestic (commercial buildings and small industry) space heating and DHW
- Industrial processes (for process heat or as a feedstock)
- Electricity generation
- Transport
    - Aviation
    - Shipping
    - Rail
    - Road – HGVs and buses

As projections[8] show that the sector is expected to be primarily served by electric vehicles (EVs) in the future, the use of hydrogen in private vehicles and small vans was ruled out from the scope at an early stage. Hydrogen could also be used for cooking in domestic and non-domestic buildings, although this is not considered separately in this study, as it does not constitute a significant proportion of demand.

The UK Low Carbon Hydrogen Standard[9] (LCHS) was published in 2023 and defines what can be considered 'low carbon' hydrogen. This can come from a number of production routes, although two are expected to make up the majority of future hydrogen production in the UK, as well as the Hub region, and are the principal focus of this study:

- Electrolysis (aka 'green' hydrogen) – using renewable electricity to split water into hydrogen and oxygen in an electrolyser
- Fossil gas reforming with CCS (aka 'blue' hydrogen) – extracting hydrogen from natural gas feedstock (as is done currently to produce 'grey' hydrogen) and capturing the CO_2 emissions

In each of the sectors listed above, in order to decarbonise through the use of low carbon hydrogen, current fossil fuel usage will need to be replaced by:

[8] Sixth Carbon Budget – Surface Transport, December 2020, CCC, Link
[9] UK Low Carbon Hydrogen Standard, December 2023, Link

a) Using a low/zero carbon version of an existing fuel or feedstock in broadly the same process or equipment, for example, replacing aviation fuel with Sustainable Aviation Fuel (SAF), or natural gas with hydrogen in heating boilers. This also includes replacing grey hydrogen in industrial processes with low carbon hydrogen.

b) A more significant change in a process or equipment used, for example, replacing coking coal with hydrogen in steel production, or replacing combustion engines with hydrogen fuel cells.

This study considers the overall end-use demand for low carbon hydrogen molecules across the region for both cases stated above, which could be in the form of pure hydrogen (gaseous or liquid), hydrogen carriers, or hydrogen-based fuels such as methanol, ammonia and some forms of SAF. The assessment of the 'hydrogen balance' across the region therefore focusses on the overall production and consumption of hydrogen molecules. However, it does not break this down into the different hydrogen-based fuels, for simplicity in the modelling. Additionally, the model primarily considers distribution of hydrogen by pipeline, other methods such as road/rail transport are considered qualitatively for some sectors.

Other scope considerations for this study included:

- The supporting infrastructure required for hydrogen assets is not considered explicitly when modelling the build out of capacity, such as Carbon Capture, Utilisation and Storage (CCUS), grid connections, geological properties, planning consent, etc.
- Blending of hydrogen with natural gas was not considered for distribution, this is partly for simplicity in the modelling, but also as it has been identified by the government as an 'offtaker of last resort', and is not expected to form a significant part of energy supply in existing gas pipelines[10].

1.4 Project Methodology

A core part of the work carried out in this study, was the development of a geospatial and temporal digital model. This customisable model can simulate the future of hydrogen supply, distribution and demand in the Hub region at different points in time.

The model is described in more detail in Section 3, but is central to fulfilling the aims of the project by allowing a range of independent datasets to be used (see Section 2), and processing these with transparent methods and assumptions. Outputs from the model show the future development of hydrogen in the region (see Section 4), upon which the action plan in Section 7 is based. The approach is shown in Figure 2.

[10] https://www.gov.uk/government/news/major-boost-for-hydrogen-as-uk-unlocks-new-investment-and-jobs

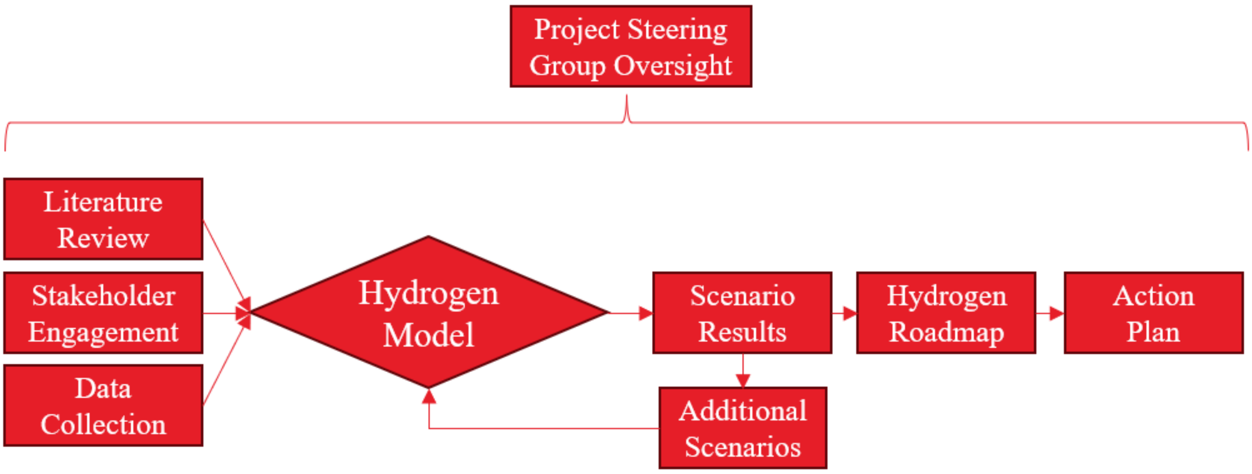


Figure 2 - Project methodology

Stakeholder engagement was undertaken throughout the project with a wide range of organisations in both the Hub and WYCA regions, which is detailed further in Section 2.

As part of the roadmap study, this project was expected to produce an evidence-based action plan for hydrogen development in the Hub region, and to identify and convene a hydrogen working group who will then take the action plan forwards, see Section 7.

1.4.1 Dependencies

The model used in this study is based on input data for planned hydrogen projects, as well as a range of assumptions relating to the evolution of hydrogen demand across different sectors in the Hub region (see Section 3 and Appendix B).

Clearly, the results and findings are highly dependent on the hydrogen assets that are assumed to be constructed. The scale of planned development within the Hub region is significant, however none of the key hydrogen asset types considered in the study have yet been deployed at scale in the UK, and also have significant dependencies on supporting infrastructure, other hydrogen projects and government policy. A recent IEA update notes that only 4% of announced projects across Europe have progressed to a final investment decision[11]. It is therefore difficult to judge whether the stated timescales, technology, scale and business models of each planned project are credible, and all projects were initially assumed to be equally likely to go ahead.

The results (and the planned hydrogen assets) also have a significant dependency on the modelled evolution of hydrogen demand, which again is currently at very early stages in most sectors, and so a range of assumptions and projections are used (as detailed in Appendix B). Some of the demand sectors require new or improved technology for widespread conversion to hydrogen, and there is also a currently limited evidence base in some sectors for the expected uptake of hydrogen compared to other technologies to achieve decarbonisation.

[11] Northwest European Hydrogen Monitor, IEA, March 2024, Link

At a wider level, the future price of hydrogen (blue or green), as well as capital and operating costs of hydrogen assets, have significant uncertainties. National, regional and local policies and funding for hydrogen projects in the UK, are also subject to change which, given the nascent state of the hydrogen sector, can have a significant impact on its future development.

The study was conducted with information available at the time, but the factors described above indicate a significant amount of inherent uncertainty in predictions of future hydrogen development/deployment. Multiple scenarios and sensitivity studies have been assessed to identify key dependencies, however data and findings presented in this report should be considered a snapshot in time, and subject to change.

2 INFORMATION GATHERING

This section summarises the key sources of data and information used in this study.

2.1 Stakeholder Engagement

Stakeholder engagement was a key part of the study. Whilst also informing regional stakeholders of the project and obtaining buy-in for it, the stakeholder engagement played a key role in iteratively improving the methodology. Through suggestions and challenges from stakeholders with local, and expert, understanding of the key sectors and parameters, we were able to adjust assumptions, highlight limitations, and utilise additional data.

2.1.1 Workshop

A wide range of stakeholders were invited to an online workshop in December 2023 (an attendee list is included in Appendix A). Organisations were invited to attend and contribute based on:

- Having some presence or involvement in the Hub region (either specifically relating to hydrogen, or decarbonisation more generally)
- Achieving a balanced mix of private and public sector representatives, as well as those from academia and other independent groups
- Having representation from those directly involved in hydrogen production, storage, distribution and the supply chain at either the larger or a smaller scale

The workshop agenda comprised:

- An introduction to the NEY Hub and the roadmap study project
- Breakout rooms for discussion of regional opportunities and challenges
- Interactive surveys
- Guest speakers: ECH, Yorkshire & Humber Climate Commission and Tees Valley Decarbonisation
- Introduction to the proposed methodology for the roadmap study and breakout room discussion session

2.1.2 Workshop Findings

Attendees were invited to take part in an interactive survey during the workshop.

When compared with the hydrogen model uptake factors derived from the literature review (see Section 3.2), Figure 3 shows that the attendees were in broad agreement that a more significant role is expected for hydrogen in industry and with a small role in domestic or commercial space heating. In other sectors (power generation and aviation), there was a greater split in opinion between whether hydrogen would play a minor or major role. Interestingly, most attendees expected that some hydrogen would be exported from the region which appears to be consistent with the balance of future supply and demand found in this study. Some uptake is expected in land transport (although this was not broken down between the sub-sectors), with a greater uptake in shipping, which is again broadly consistent with the literature review findings.

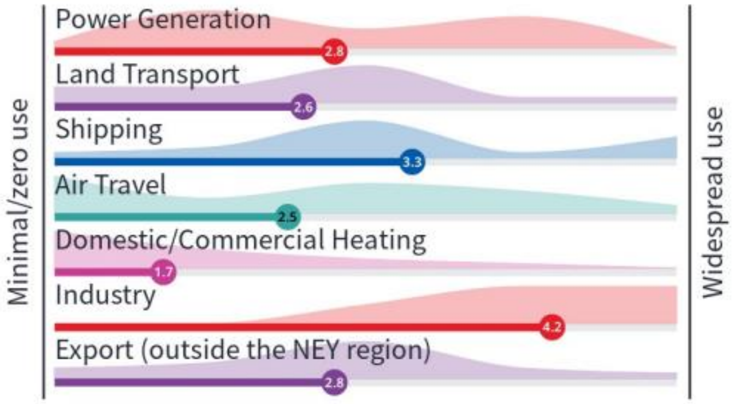


Figure 3 - Responses to "in the NEY region, what proportion of demand do you think hydrogen will fulfil in these sectors?"

The majority of attendees were directly involved in hydrogen development and were well aware of the opportunities and challenges relating to their sector. Figure 4 shows how the opportunities for hydrogen were understood as being focussed on the end-users, with some acknowledgement of how the Hub region could become a leader in the UK, and that the hydrogen transition would bring employment benefits. A wide range of challenges were highlighted. These included the practical difficulties of implementation, issues with societal acceptance, the uncertainty with, or delays in, funding and policy, and the interdependence of the public and private sector.

"What are the opportunities for hydrogen in the NEY region"

"What are the challenges for hydrogen in the NEY region?"

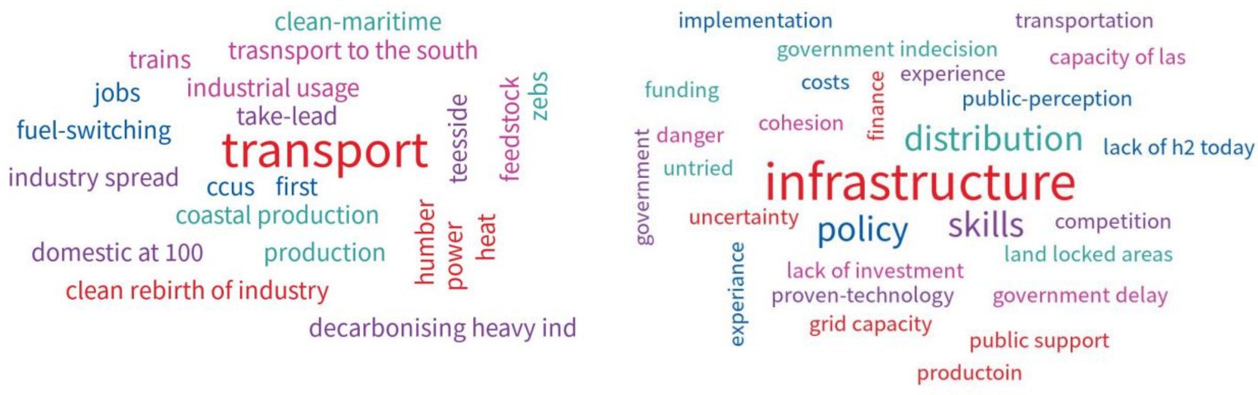


Figure 4 - Responses to additional survey questions

The first breakout session highlighted the range of organisations required to ensure effective deployment of hydrogen (covering a similar range to the criteria noted in Section 2.1.1). It was noted by several attendees that local government could be a valuable neutral/unbiased facilitator of the communication and forums between different stakeholders and could help raise public awareness and acceptance of hydrogen. There was unanimous agreement that whilst there was already a skilled workforce in the region, a higher volume of workers would be needed, and that some upskilling would be required to deliver the expected range and scale of hydrogen projects.

The second breakout session focussed on the modelling methodology and availability of data. This highlighted some existing additional studies and datasets for consideration in the literature review, as well as reinforcing what were seen as some of the key factors that would affect hydrogen uptake in the future (government policy and funding, hydrogen cost, and decisions on uptake in specific sectors such as heating).

2.1.3 Ongoing Stakeholder Engagement

Following the workshop there was further engagement with a range of stakeholders (including those who could not attend) throughout the course of the project. An additional workshop specific to the WYCA deep dive study was also carried out in January 2024, with feedback from both contributing to the overall project approach.

NEY Hub and WYCA steering groups (comprising representatives from each CA, LEP or LA) provided guidance throughout the project. A hydrogen working group, formed of key regional stakeholders identified throughout the project, is to be convened to progress the identified actions – see Section 7.2.

2.2 Literature Review

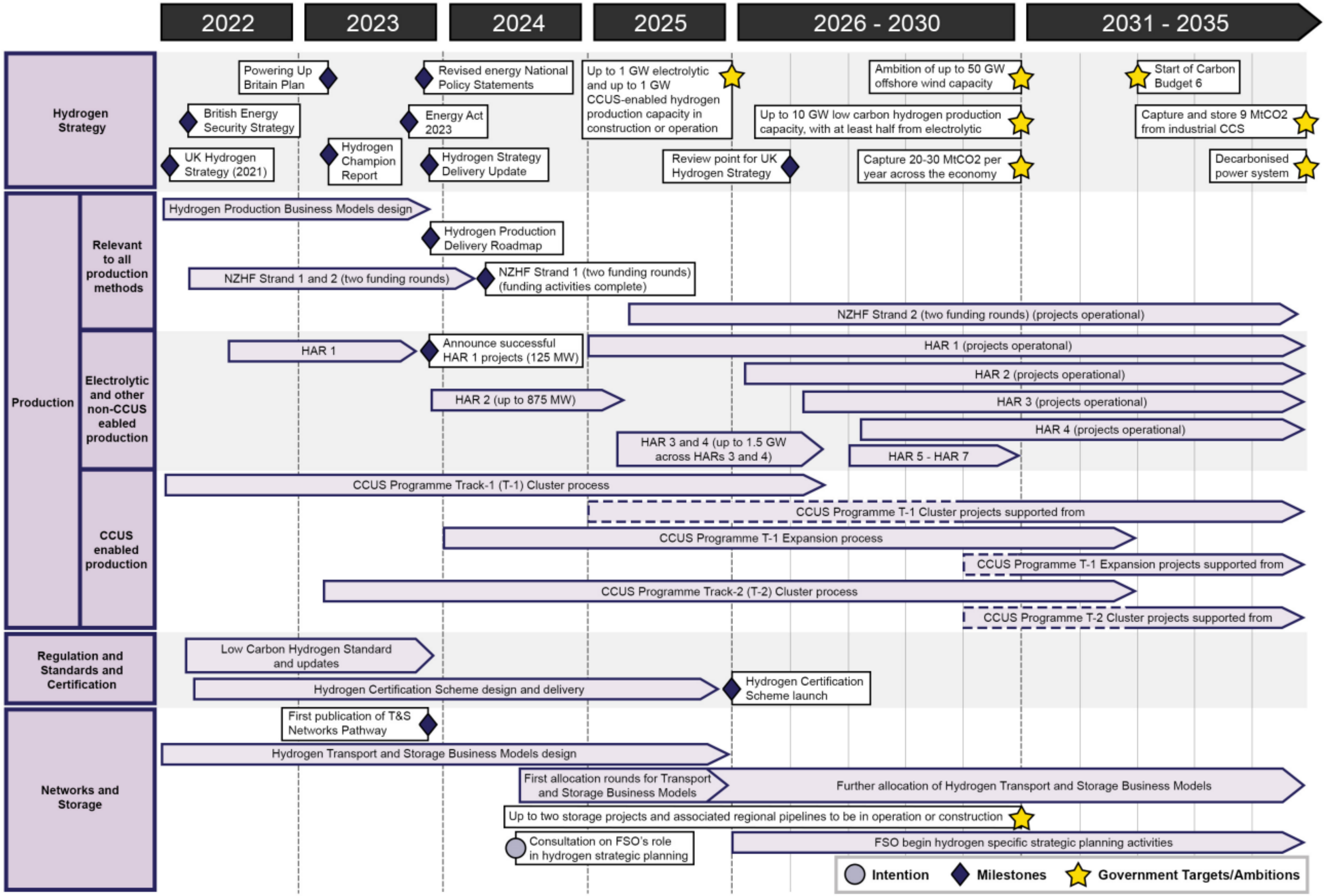
Relevant literature in three principal areas was reviewed to provide data, evidence and context for this study:

1. Existing reports and studies on the development of hydrogen in the Hub region (or specific areas) – see Appendix A.1.2
2. Evidence for expected hydrogen uptake and feasibility dates in different sectors – see Appendix A.1.3
3. Current and upcoming policy, strategies and funding that could influence hydrogen development in the Hub region – see below.

2.2.1 Policy Context

Figure 5 is an extract from the latest UK hydrogen strategy update, which summarises the range of strategy, policy and funding strands currently in place or planned. This wide array of initiatives has been introduced in the last few years to support the UK hydrogen economy and is also summarised in the IEA 2024 Outlook[12]. The relevance of these and other key hydrogen-related items for the Hub region is discussed in Table 1.

[12] Northwest European Hydrogen Monitor, IEA, March 2024, Link



NZHF - Net Zero Hydrogen Fund; **HAR** - Hydrogen Allocation Round; **CCUS** - Carbon Caputre, Usage and Storage; **T&S** - Transport and Storage; **FSO** - Future System Operator

Figure 5 - UK hydrogen strategy roadmap

Table 1 – Key government policy and funding for the Hub region

Item	Relevance for hydrogen development in the Hub region
UK Hydrogen Strategy	• Sets ambitious goals for low carbon hydrogen production – 5 GW in construction or operation by 2025 and 10 GW by 2030 (half to be green) • If built, planned production in the Hub region would comprise a significant proportion of this target
Energy Act 2023	• Introduced business models providing revenue support for production, transport and storage of hydrogen (see below) • Regulatory framework for CO2 transport and storage (key to the industrial clusters and blue hydrogen production)
Low Carbon Hydrogen Standard	• Defines what constitutes low carbon hydrogen • Upcoming Hydrogen Certification Scheme to demonstrate compliance and ensure a level playing field, also facilitating hydrogen import/export
Hydrogen Production Business Model	Provides revenue support to producers of low carbon hydrogen, reducing the cost premium to high carbon fuels (e.g. natural gas). Currently delivered via two funding streams: • Hydrogen Allocation Rounds – revenue support for green hydrogen production over 15 years. Delivered in phases, HAR2 is currently being evaluated with HAR3-7 planned (scale and other criteria will be refined). • Net Zero Hydrogen Funding – support for design and development costs or CAPEX of low carbon hydrogen production projects (blue or green). Further information available in the Hydrogen Production Delivery Roadmap
Hydrogen Transport and Storage Business Model	• Will provide revenue support for hydrogen distribution (i.e. pipelines) and storage facilities – which will impact key distribution and storage projects in the Hub region
CCUS Cluster Programme	• Provides support for CCUS projects in industrial clusters, which is required for blue hydrogen production projects • East Coast Cluster (covering Humber and Teesside) selected as a Track 1 cluster, aiming to deploy CCUS by the mid-2020s
Net Zero Strategy: Build Back Greener	• Sets out commitments to decarbonise electricity generation by 2035 (now intended to be brought forward to 2030) • Also includes commitments on hydrogen production and use, although superseded by the UK hydrogen strategy (see above)
Other funding / support mechanisms	There is a wide range of schemes covering specific sectors and technologies – see Table 1 in the Hydrogen Strategy Market Update

As well as the policies already in place, there are some key upcoming decisions to be made by the UK government that could affect hydrogen development in the Hub region:

- A SAF mandate for aviation fuel (with targets and limits on the proportion of different pathways) is due to be introduced at the beginning of 2025[13].
- Blending of hydrogen in the natural gas grid (up to 20% by volume) has been supported, a decision on enabling this is due to be taken in 2025/26[14].
- A decision on the role of hydrogen in space heating (domestic and commercial) is due to be made in 2026[15].

These have been taken into account in the modelling of future hydrogen demand, as discussed in Section 3 and Appendix B.

2.2.2 Local and regional strategies and policies

In addition to national policy, regional or local strategies have also been defined by each of the Hub's constituent members relating to hydrogen. These are listed in Table 2 and indicate where hydrogen is expected to play a role for each member as part of the overall energy or climate strategy.

Table 2 – Hub member policy or strategy documents

Hub Member	Strategy Document	Date
North East CA	Energy for Growth Strategy	
Tees Valley CA	Net Zero Strategy for Tees Valley	March 2023
York and North Yorkshire CA	Routemap to Carbon Negative	January 2023
Hull and East Yorkshire Business Growth and Skills Hub	Economic Growth & Workforce Wellbeing Strategy	February 2022
West Yorkshire CA	West Yorkshire Climate and Environment Action Plan	October 2021
South Yorkshire MCA	Energy Strategy	January 2022

2.3 Energy Demand Data

Data on the current energy demand that could be replaced by hydrogen for the in-scope sectors (see Section 1.3.2) was obtained from primarily public datasets, further detail is provided in Appendix A.1.3. This provides the baseline from which the model estimates future hydrogen demand (see Section 3).

[13] Sustainable aviation fuel initiatives, July 2024, Link
[14] Hydrogen blending: strategic decision, December 2023, Link
[15] Hydrogen heating: overview, March 2024, Link

2.4 Hydrogen Asset Data

Data were gathered on key parameters for planned projects within the Hub region relating to the construction & operation of hydrogen production, distribution and storage assets. Publicly announced projects with an indicated operation date and sufficient information on the scale of the project were considered in this study. The Hydrogen UK project database was the main source of production information, alongside additional context from Arup experts and the literature review.

The Hub region contains a particular concentration of planned hydrogen projects, across all technology types and scales. A summary of all projects used in the modelling is provided in Appendix A.1.4, Table 3 highlights some examples of the different types.

Table 3 - Highlighted hydrogen projects in the Hub region

Project	Description	Involved partners
H2H Saltend	Large scale blue hydrogen production (0.6 GW) located at, and plans to supply hydrogen to, the Saltend Chemicals Park, within the Humber industrial cluster.	Equinor
HyGreen Teesside	Large scale green hydrogen production (0.5GW) located in the Teesside industrial cluster to supply industrial and other local demands. Being built in two phases, HyGreen aims to be producing hydrogen in 2025.	bp
Bradford Low Carbon Hydrogen	Small scale green hydrogen production (25 MW), located in Bradford to supply local transport and other demands. Supported by HAR1 funding, it is currently the only firm production project in West Yorkshire.	Hygen and N-Gen
Aldbrough Hydrogen Storage	This project is based on the salt cavern storage technology, which is one of the only viable methods of storing large quantities of hydrogen for long periods of time. Aldbrough aims to be operation in the early 2030s.	SSE Thermal and Equinor
East Coast Hydrogen (ECH_2)	ECH_2 is a major project looking at identifying and delivering the gas network infrastructure that can connect hydrogen producers, end users, and storage assets in the East Coast region.	Cadent, National Gas, and Northern Gas Networks

This data is then used by the hydrogen model (see Section 3) to simulate the development of these assets through time, alongside potential hydrogen demands. As noted in Section 1.4.1, the findings from this study are highly dependent on the planned deployment of assets. At this stage, the public plans for timescales and capacities for each project have been used as a starting point, with some of the scenarios (see Section 3.3) then investigating how variations in these may affect hydrogen deployment.

3 HYDROGEN DEVELOPMENT MODEL

This section is intended to provide a high-level overview of the hydrogen model and introduce key terms – further detail is provided in Appendix B.

3.1 Modelling Methodology

The purpose of the model is to take the data on current energy demand and known, planned hydrogen asset development (see Section 2), combine this with assumptions on hydrogen uptake and show how the overall picture of hydrogen supply, distribution and demand may evolve through time in the Hub region.

The model works on a yearly basis, running from 2023 to 2050. In each year, the model performs the following steps, shown graphically in Figure 6:

a) Showing the location and scale of hydrogen assets as they are developed, in line with planned deployment through time.
b) Calculating the expected hydrogen demand at specific sites/locations through time; using the current energy as a baseline, and then taking into account sector growth, availability of hydrogen technology, uptake within each sector and how hydrogen is used at the site to replace fossil fuels.
c) For each site where there is a hydrogen demand, determining whether there is a supply of hydrogen in the vicinity that it can economically connect to, thereby modelling the organic growth of a hydrogen network (or multiple independent networks).
d) For sites that are not supplied hydrogen, identify 'mini clusters' where local production could be considered (see Appendix B for more detail).

For step b) – two independent methods (top-down and bottom-up) are used to estimate overall hydrogen demand at the Hub level, for each sector, which provides a degree of verification. These methods are discussed in more detail in Appendix B.

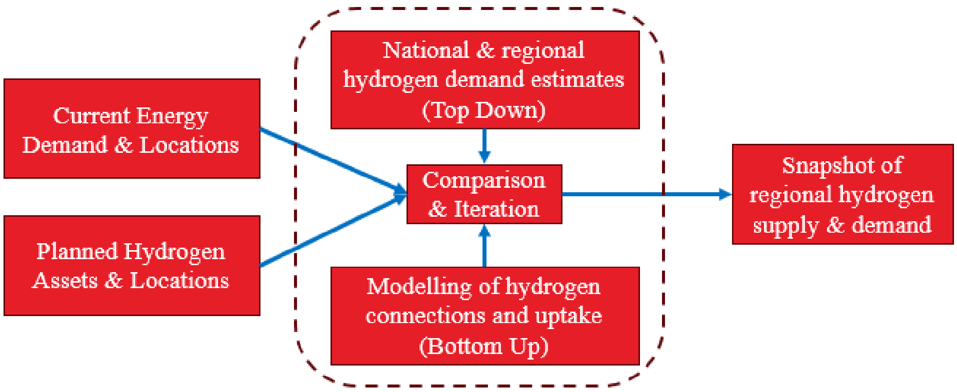


Figure 6 - Hydrogen model overview

The model is setup in Microsoft Power BI, which performs the steps listed above and uses a front-end dashboard (see Figure 7) to display the modelled hydrogen assets on a map of the region, as well as other key outputs and statistics. The scenarios used in this study can be selected and custom combinations can also be defined by selecting which assets should be included.

The hydrogen model and dashboard have been provided to the Hub, WYCA and the hydrogen working group to support future assessments and activities.

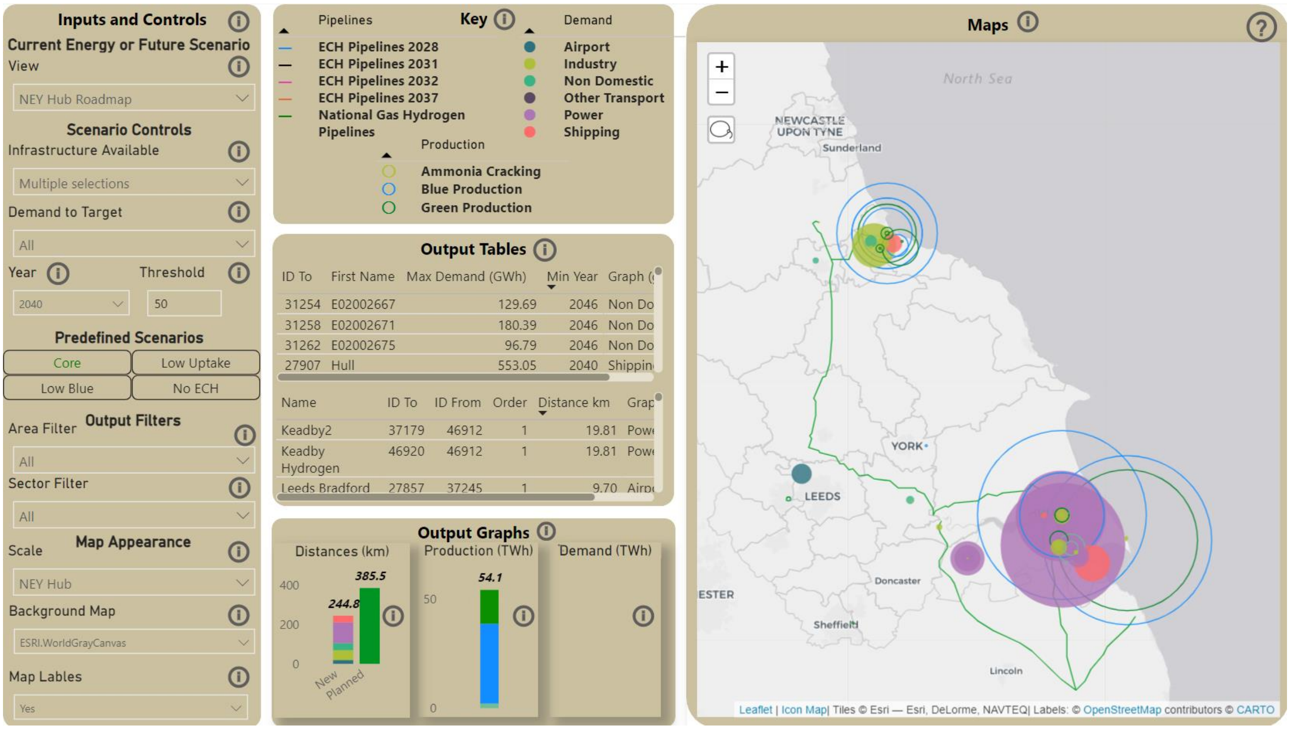


Figure 7 – Hydrogen model dashboard and mapping

3.2 Hydrogen Demand

A key factor within the model, and the overall roadmap study, is the assumed hydrogen uptake for each sector/site in the Hub region. As part of the literature review, data or estimates for each sector from national and regional studies into future hydrogen demand were obtained. A wide range of sources were considered in order to provide an independent, evidence-based estimate for each sector. The estimate takes into account efficiency improvements, the relative efficiency of hydrogen vs. the current fuel and, perhaps most importantly, the expected role of hydrogen vs. alternative decarbonisation technologies (as this is not modelled explicitly). Uptake factors were then modified to take into account Hub-specific factors, such as known site/sector plans, to ensure they were as representative as possible.

Further detail on the methodology and the uptake factors used in the model are provided in Appendix B. These broadly follow the national/regional estimates from other studies, with some key differences based on location and site-specific information as noted below:

- Adjustments were made to account for specific large sites planning to use or not use hydrogen, such as the Saltend & Immingham power stations using hydrogen (in part) for baseload power, Scunthorpe steelworks planning to replace blast furnaces with electric arc furnaces, and some sites in the industrial clusters intending to use CCUS.
- A higher average uptake has been assumed in some industrial sectors, given the expected availability and proximity of hydrogen supply in the Humber and Teesside industrial clusters.
- A very low uptake of hydrogen in space heating & DHW (domestic and non-domestic sectors, including in district heating schemes) has been assumed. This follows the government decision to cancel the hydrogen village trial and an assumed low likelihood of hydrogen for heating being supported (when a government decision is made in 2026), given currently available evidence[16].

3.3 Scenarios

As noted in Section 1.2, there are currently a wide range of estimates for future hydrogen uptake in the UK (for example in CCC and FES modelling), primarily due to the uncertainty in future costs, constraints, and technology development. In addition, within the Hub region there are specific hydrogen projects and certain technologies that are expected to play a significant role in the overall hydrogen transition, and changes in these could have a big impact on development. Different scenarios have therefore been assessed to understand the potential range of outcomes for hydrogen uptake in the Hub region. The current range of planned projects are incorporated in Scenario 1 and therefore, this could be considered the most optimistic scenario of production and distribution (as most projects have not yet reached FID stage, and may be subject to change). Other scenarios (see Table 4) then consider high level variations in areas that hydrogen development in the Hub region is particularly dependent on, with the rationale for each discussed in more detail in Section 4.

In reality, the changes assessed in the scenarios would likely have further knock-on effects, for example, a reduction in demand may reduce the level of production that could be justified in the region. The hydrogen model does not assess these feedback loops directly given their complexity, and so these implications are discussed qualitatively for each scenario in Section 4. These scenarios are considered sufficient to inform the range of potential outcomes across the Hub region at a high level, further sensitivity studies can be performed using the model dashboard.

[16] A meta-review of 54 studies on hydrogen heating, J.Rosenow, January 2024, Link

Table 4 - Scenarios assessed in this study

Scenario	Hydrogen Development Assumptions		
	Production	**Distribution**	**Demand**
1 - Planned Projects	Announced Projects	Announced projects (Project Union and ECH)	Best-estimate uptake factors
2 - Reduced production	Reduced blue hydrogen capacity	As Scenario 1	As Scenario 1
3 - Reduced demand	As Scenario 1	As Scenario 1	Uptake reduced in some sectors
4 - Reduced distribution	As Scenario 1	Not including ECH	As Scenario 1

3.4 Modelling Simplifications

The hydrogen model created for this study is inevitably a simplification of the complex future hydrogen economy, with inherent limitations and uncertainties. The simplifying assumptions used are judged to be appropriate given the relatively high-level results required to inform this roadmap study. Further detail on the methodologies used for the top-down and bottom-up methodologies are given in Appendix B, with the key points for consideration including:

- The model uses a value for each sector (specific to the Hub region) which defines future hydrogen uptake, and does not calculate this dynamically. The uptake value is derived outside the model from the literature review process and implicitly takes into account relative cost, technological feasibility, and other factors to estimate the role of hydrogen vs. alternative low carbon energy sources for a given sector.
- The hydrogen uptake value is an average for each sector, although individual site factors are used where specific plans are known.
- Large demand sites are considered individually. Domestic and non-domestic demand is aggregated at an MSOA level based on the available data.
- Capacity and constraints of supporting infrastructure for hydrogen assets are not explicitly considered (as noted in Section 1.3.2) and it is therefore assumed that a given project will have access to the required infrastructure and be able to commence operation on the planned date.
- The model does not place a constraint on the build-out of hydrogen assets in each year, which, in reality, may be restricted by available capital, workforce or equipment.
- The model assesses hydrogen supply and demand on a yearly basis and it is assumed that there is sufficient peak capacity and storage in the network to satisfy seasonal demands.
- Low carbon hydrogen is treated interchangeably within the model and it is assumed that any required purification (on entry or exit from the hydrogen network) is carried out by producers or users.

4 HYDROGEN DEVELOPMENT IN THE HUB REGION

This section presents the outputs and findings from the model. Sections 4.1 - 4.4 show how hydrogen develops in the Hub region for each of the assessed scenarios, covering the range of future development of hydrogen in the Hub region. Section 5 then summarises the results and discusses overall findings for the Hub region.

The evolution of hydrogen is shown in most detail for Scenario 1 (planned projects), where developments in a number of key years are discussed. Results for other scenarios are then presented for specific years where there are notable differences. The results for all scenarios, at all timepoints, can be reviewed in the model dashboard.

In each scenario, four key results are presented from the model which are described below to assist with interpretation:

1) Map of hydrogen production, demand and distribution

An example of the mapping output, based on the bottom-up methodology, is shown in Figure 8. All modelled hydrogen production sites (circle outlines) and distribution pipes (coloured lines) are shown if expected to be operational in the relevant year. Where known, the development phases of each asset are shown separately. Connected demands (filled circles) show where sites with a hydrogen demand are able to be supplied, although any additional pipelines required to join these to the nearest supply point (node on the active distribution or production infrastructure) are not shown. Due to the concentration of production and demand in some locations, there is inevitably some overlap when viewed at a whole-Hub level. Further detail can be seen in the model dashboard which has a range of options to interrogate specific sites or filter the results.

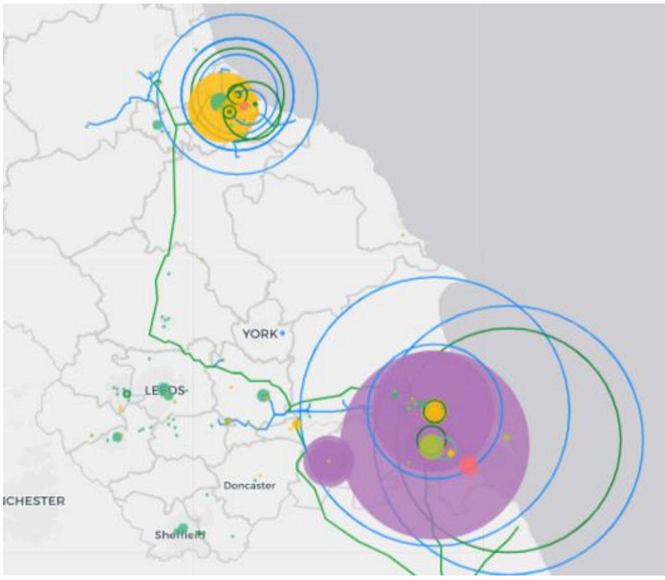


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Figure 8 – Map-based output example

north east & yorkshire
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2) Hydrogen production and demand balance

A graph is shown for each scenario comparing:

- Hydrogen output of the planned production projects
- Total possible hydrogen demand, based on the sectoral or site-specific hydrogen uptake factors
- Total connected demand (as determined by the bottom-up methodology described in Appendix B)

The possible hydrogen demand will exceed the connected demand in most years. This is primarily where smaller demands are too far away and not commercially viable to connect via a pipeline to the wider distribution network. The clearest example of this in the results is the non-domestic demand. As the distribution network expands through time, demands previously not able to connect may become close enough to justify connection.

As the Hub region is not a closed system, with options for export of hydrogen, production projects are not restricted to match demand and the balance is qualitatively discussed for each scenario. On the other hand, when limited production is modelled, the demand is restricted.

Transport and domestic demand are not shown in specific locations but are included in the supply/demand balance numbers and graphs (with possible and connected demand being set at the same value). This is a result of these sectors being better represented using the top-down methodology:

Domestic: Hydrogen for heating has a low uptake factor and is assumed to be concentrated near to hydrogen supplies, in properties that are less suited to alternative options such as heat pumps. The model does not break down the MSOA domestic demand to this level (and is covered in more detail by other studies such as LAEPs) and the top-down uptake factor is therefore used to ensure the overall expected demand across the region is accounted for.

Land Transport: Each petrol station and bus depot within the model has a relatively small demand after the uptake factor is applied. Few would therefore meet the connection threshold to be supplied via pipeline in the model. In reality, refuelling stations are likely (at least initially) to be supplied with deliveries from production sites by road/rail or potentially utilise a smaller onsite electrolyser (such as the Rotherham station). The top-down uptake factor is therefore used to reflect the correct proportion across the region.

3) Locations for additional production

Based on the methodology in Appendix B.1.5, locations for additional green hydrogen production are identified in each scenario for sites not connected to the hydrogen network.

4) Economic analysis

The investment and jobs required for the development of the planned hydrogen assets and end use conversion are calculated at a high level in this study. This analysis follows the methodology described in Appendix C. These figures are intended to show the magnitude of expenditure and/or funding required in the Hub region for further interpretation and evaluation.

4.1 Scenario 1 – Planned Projects

Results are presented for key years (2025, 2028, 2030, 2032 and 2040) where significant changes take place in the production, consumption or distribution of hydrogen in the Hub region.

4.1.1 2025

Figure 9, the regional hydrogen summary, shows that there are a number of smaller green hydrogen production plants spread across the region that are expected to be operational in 2025: HyGreen Teesside, Tees Valley Net Zero Hydrogen, Aldborough Hydrogen Pathway, Tees Valley Transport Hub and Bradford Low Carbon Hydrogen). With no hydrogen pipelines yet constructed, each production site would be independent with supply/demand balanced locally.

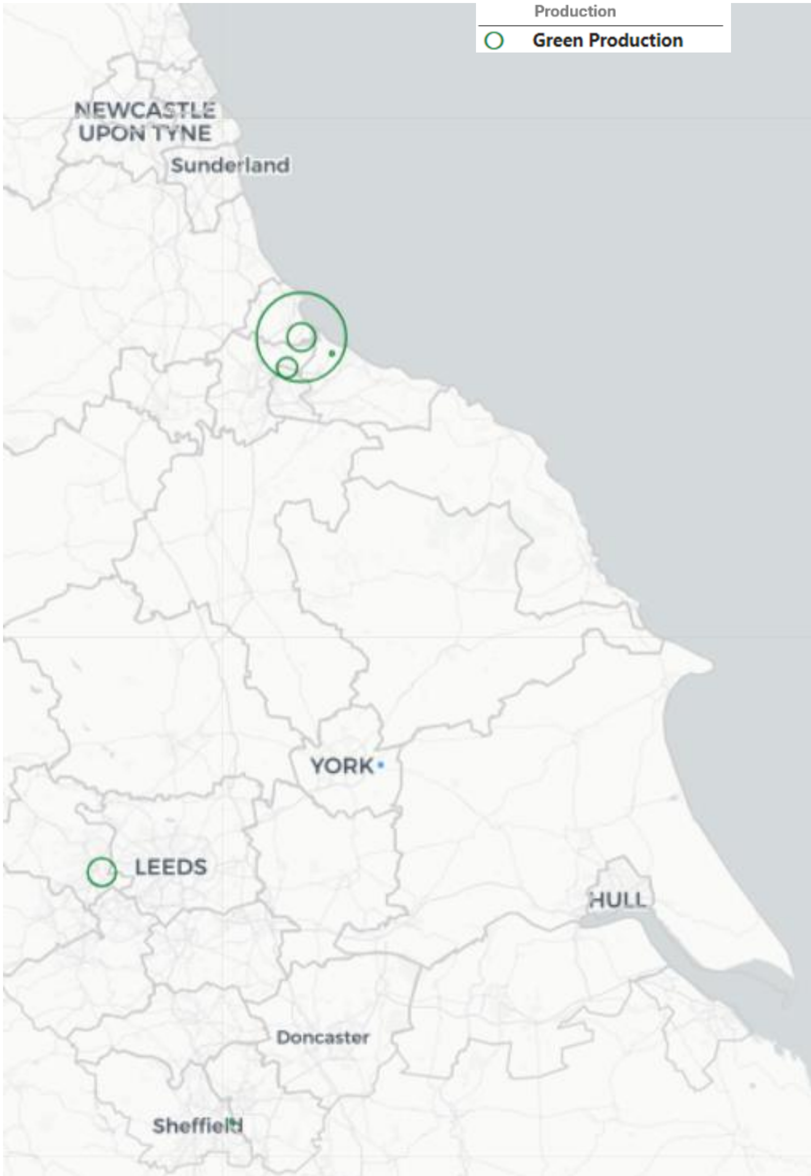

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Figure 9 - Hydrogen supply and demand points in 2025

Figure 10, presenting the balance of production and demand, shows limited potential demand predicted in the Hub region in 2025, as wide scale adoption is not yet expected in any sectors. The early predicted demand is expected to come from early adoption or trials in the transport sector (HGVs and buses), and the industry that has agreed to become an early offtaker to the green production sites. Figure 10 indicates that planned production (totalling 1.1 TWh) would significantly exceed demand in the region. Early industrial offtakers, likely to also have agreements with these early production sites, will likely absorb the rest of this excess production, however, the model only outputs demand (matching the production output of a site) if the production is all accounted for. As noted in Section 4, transport demands (particularly at this early, low volume stage) would be mostly supplied by tube trailer deliveries or direct refuelling at the production sites.

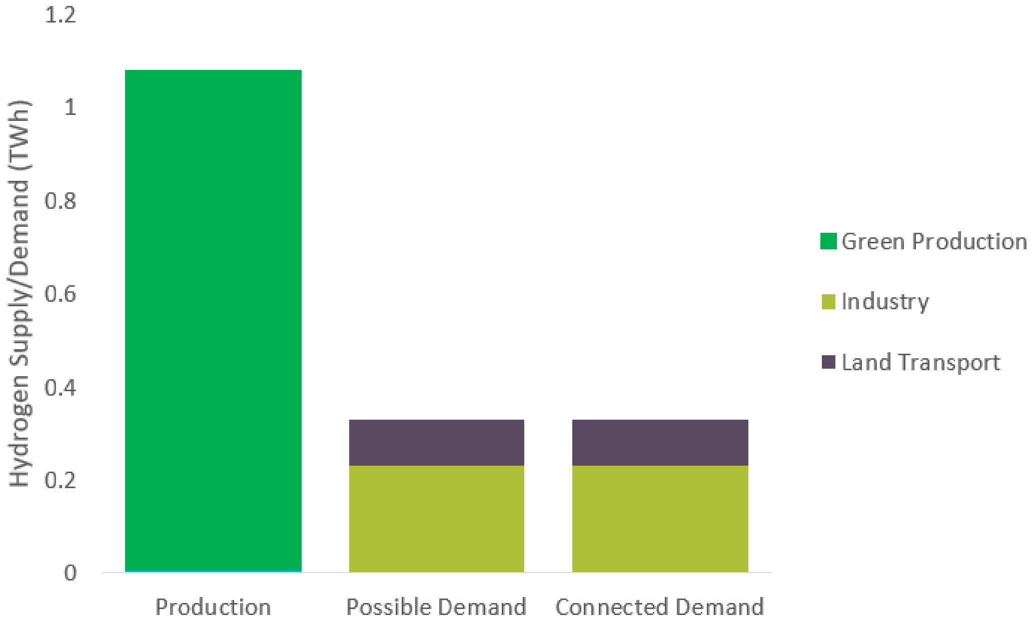

Figure 10 – Regional hydrogen balance in 2025

4.1.2 2028

Figure 11 shows the regional hydrogen map. This highlights the significant change that is planned to take place within the space of a few years: mainly large blue hydrogen production projects in the Teesside and Humber clusters (including Easington) becoming operational. The first phases of ECH (part of National Gas' and NGN's hydrogen pipelines) are expected to be completed by 2028, adding 640 km of pipeline and facilitating the bulk transfer of hydrogen between Teesside and Humber. This will also provide connections to some large industrial sites in the vicinity of the pipelines (e.g. in the direction of Leeds and Doncaster).

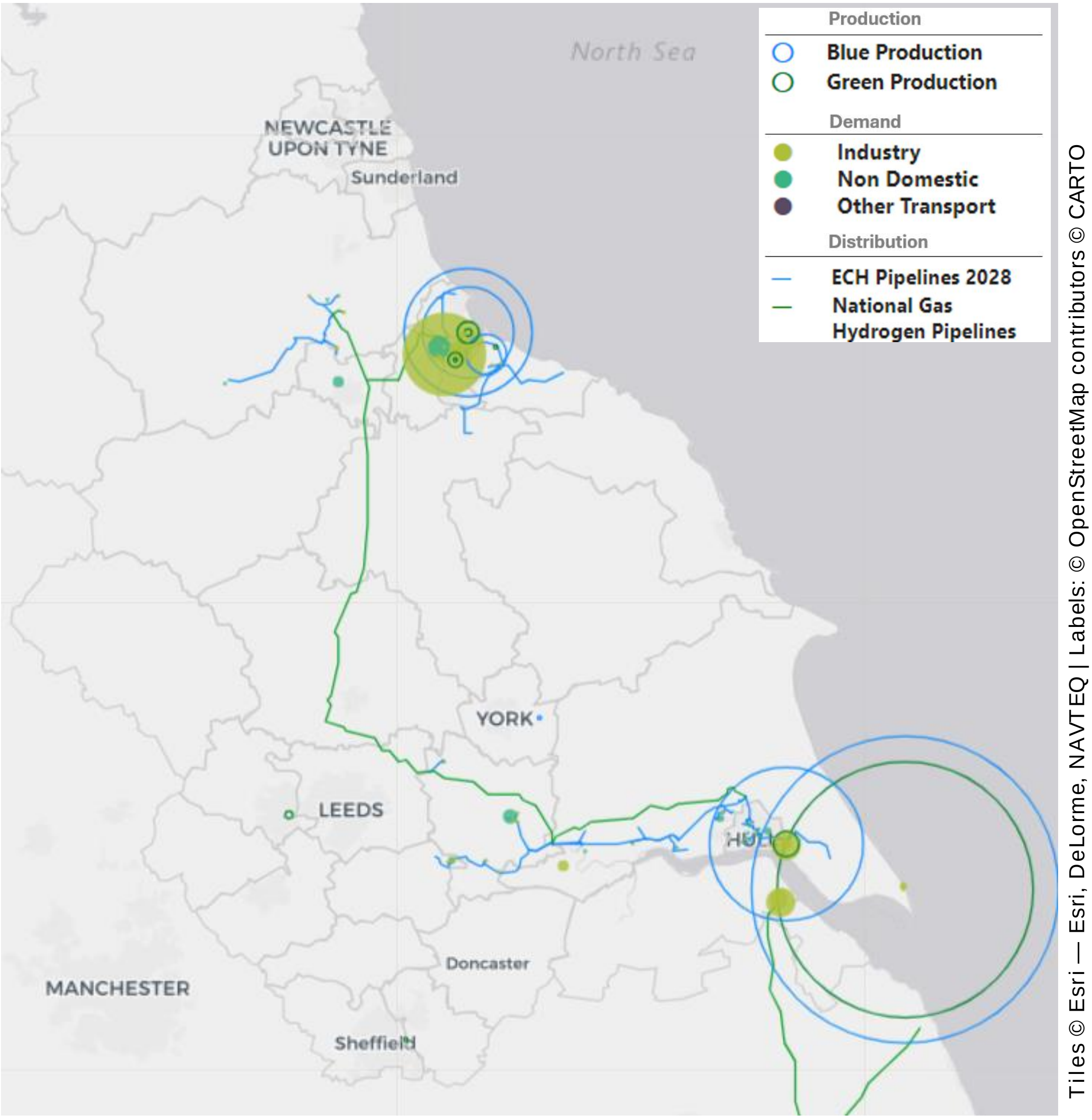

Figure 11 - Hydrogen supply and demand points in 2028

Figure 12 shows the balance of production and demand - with an order of magnitude increase in both expected compared to 2025.

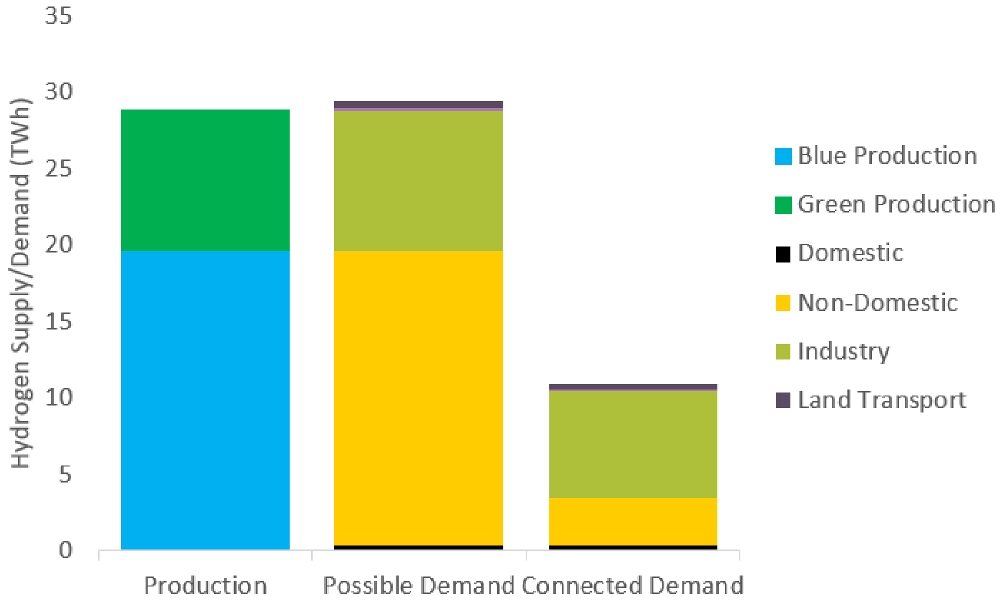

Figure 12 - Regional hydrogen balance in 2028

Production (+28 TWh from 2025)

By 2028 the Easington Hydrogen and Humber H2ub projects, as well as the first phases of H2H Saltend, H2NorthEast and H2Teesside are expected to be operational, adding significant blue hydrogen capacity. Green hydrogen is expected to account for around 1/3 of production following the commissioning of the first large green hydrogen project at Easington as well as a number of smaller plants.

Demand (+11TWh from 2025)

By 2028 fuel switching to hydrogen is expected to be commercially available for several sectors, with demand volume driven by some large industrial sub-sectors and non-domestic sites. This leads to a large increase in potential hydrogen demand within the Hub region, although as shown in Figure 11, not all of this can yet be supplied without an expansion of the hydrogen distribution network. Additionally, favourable economics would also likely be required in the non-domestic sector, to justify commercial sites adopting hydrogen.

Planned production significantly exceeds connected demand in 2028. As before, this excess could be exported outside the region (particularly with National Gas' pipeline operational) or provide some buffer if large, individual projects are delayed.

4.1.3 2030

Figure 13 shows the regional hydrogen map in 2030. The second phase of ECH is expected to be under construction, so the wider distribution network in the Hub region is not yet significantly different, with changes focussed on the Teesside and Humber cluster regions. Here, additional large production plants are expected to be operational as well as further significant demands from the power sector.

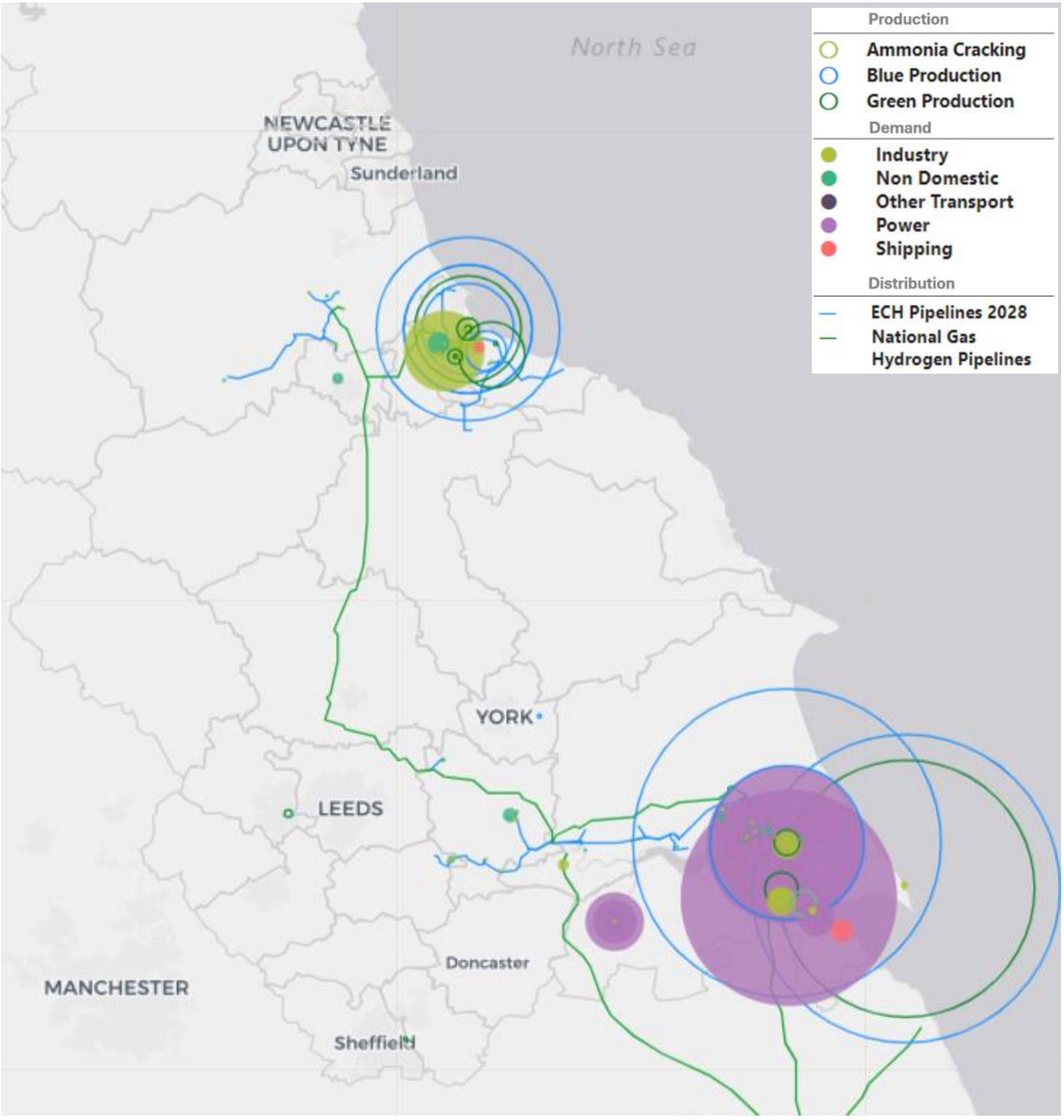

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Figure 13 - Hydrogen supply and demand points in 2030

Figure 14 shows the balance of production and demand, with further significant increases in both compared to 2028.

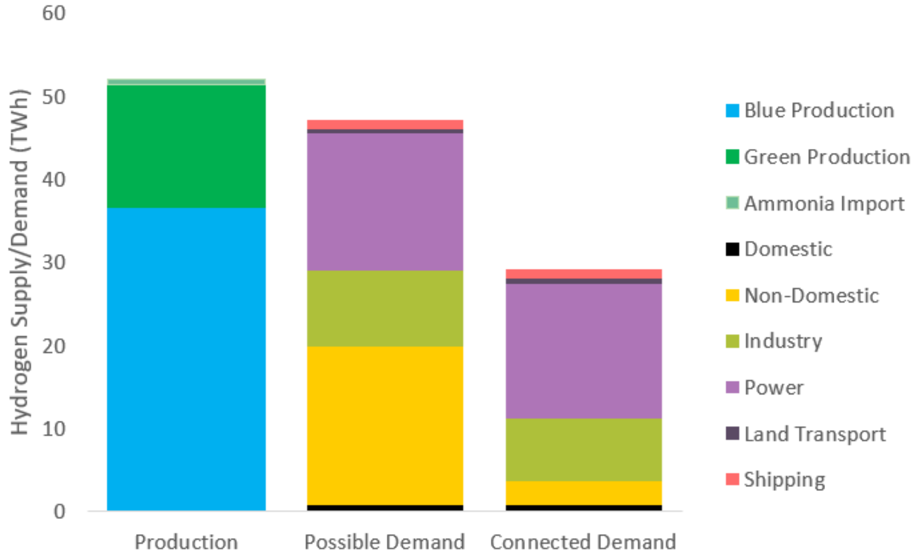

Figure 14 – Regional hydrogen balance in 2030

Production (+23 TWh from 2028)

An additional 17 TWh of blue hydrogen and 6 TWh of green hydrogen is produced from plants expected to be operational by 2030. Growth in green hydrogen is driven by large facilities in Teesside (Wilton and HyGreen Phase 2). The total planned capacity within the Hub region increases to 7.4 GW, meeting the majority of the UK government target for 10 GW of low carbon hydrogen production by 2030. An ammonia import and conversion terminal in Immingham is also expected to be operational, providing low carbon hydrogen whilst diversifying the production mix.

Demand (+18 TWh from 2028)

By 2030 fuel switching to hydrogen is expected to begin within the power generation sector, with partial conversion of the large plants at Immingham and Saltend as well as other peaking plants (for use in grid balancing) driving the significant increase in overall demand. The adoption of hydrogen-based fuels for shipping is also expected to begin in 2030, adding further demand in the Humber region (although in the form of ammonia/methanol). There are limited changes in other sectors, although the quantity of hydrogen used in transport and domestic buildings continues to increase. As before, not all the potential industrial demand can yet be met (as noted in the introduction to Section 4).

Planned production again exceeds demand, by a similar margin to 2028.

4.1.4 2032

Figure 15 shows the regional hydrogen map in 2032. The second phase of ECH is complete (an additional 650 km of pipeline), allowing supply to extend further inland in the region to Leeds, Bradford, Doncaster and industrial sites in Knottingley.

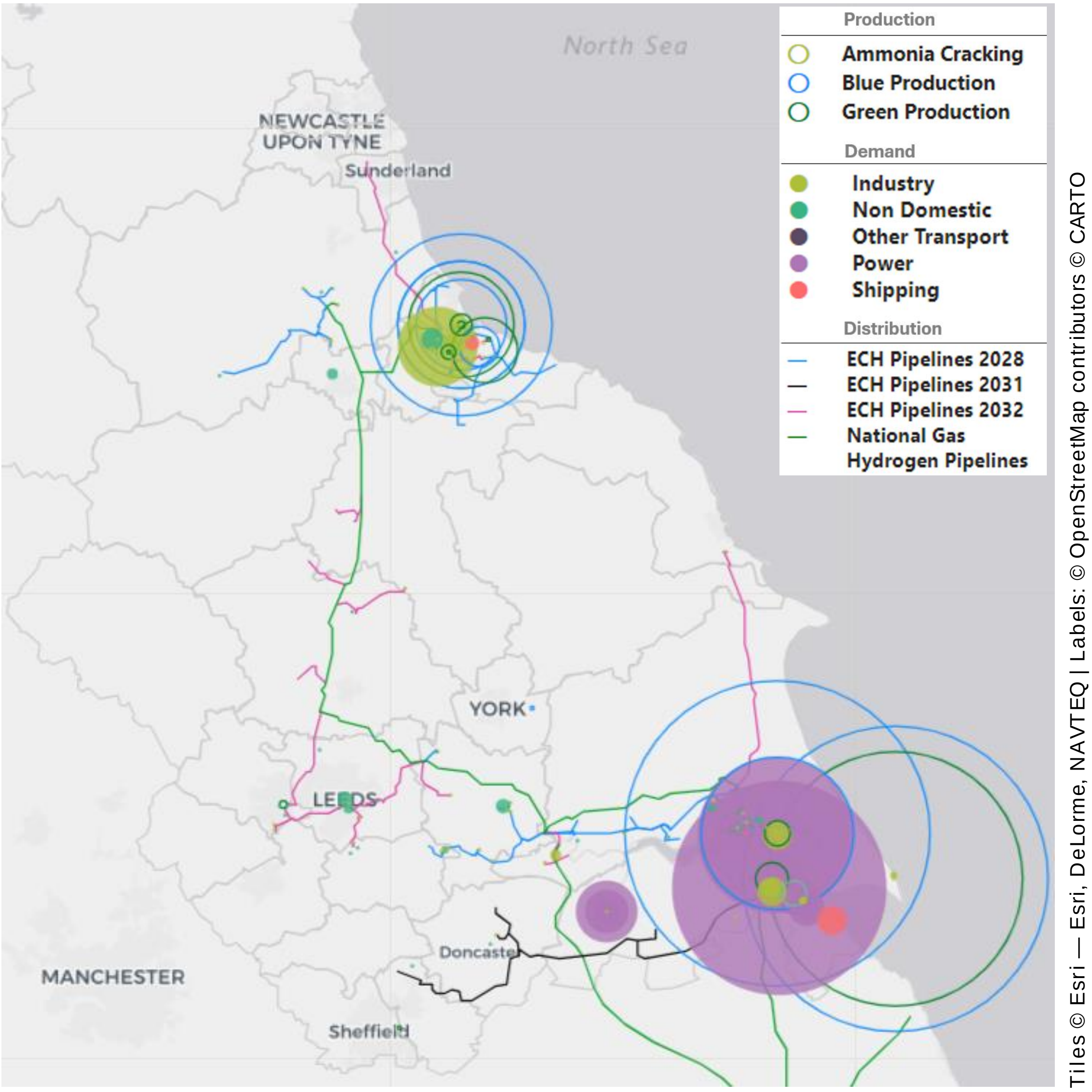

Figure 15 - Hydrogen supply and demand points in 2032

Figure 16 shows the balance of production and demand. No additional sectors are assumed to switch to hydrogen between 2030 and 2032 and the possible demand does not therefore change significantly. The new ECH pipelines, however, do allow sites further inland to now connect, increasing the total connected demand relative to 2030.

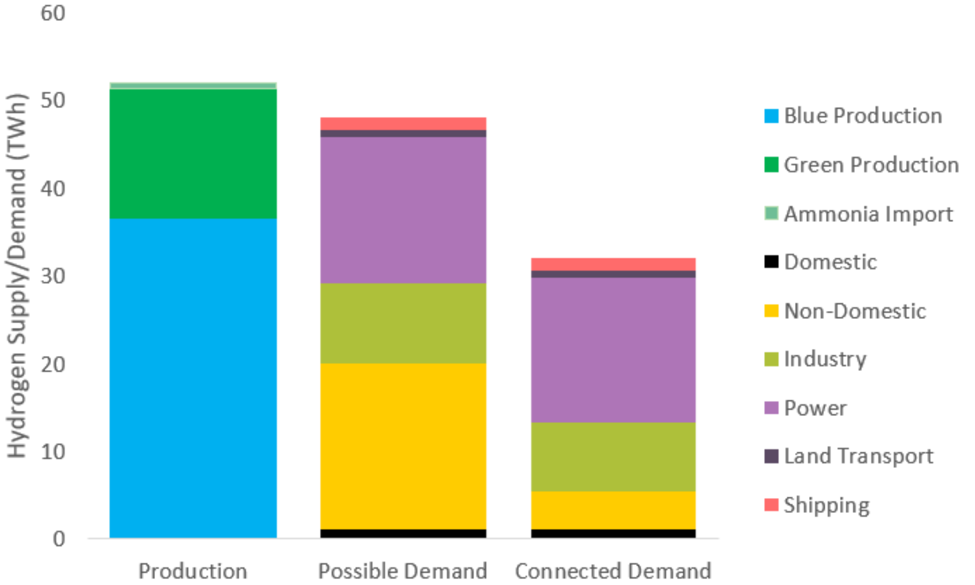

Figure 16 – Regional hydrogen balance in 2032

Production (+0 TWh from 2030)

No additional production is planned to be operational between 2030 and 2032.

Demand (+3 TWh from 2030)

Increases in demand occur in the non-domestic and industrial sector, enabled by the expansion of the ECH network which allows new sites to be connected. Hydrogen demand in shipping grows (and continues to do so through to 2050) as the proportion of vessels using hydrogen-based fuels increases.

4.1.5 2040

2040 is chosen as the final year to display as all currently planned hydrogen projects are expected to be operational by this point and Figure 17 shows the regional hydrogen map. The final phase of ECH is completed in 2037, providing an additional 160 km of pipeline for hydrogen distribution which includes a number of inland spurs, generally connecting to specific industrial sites and urban areas.

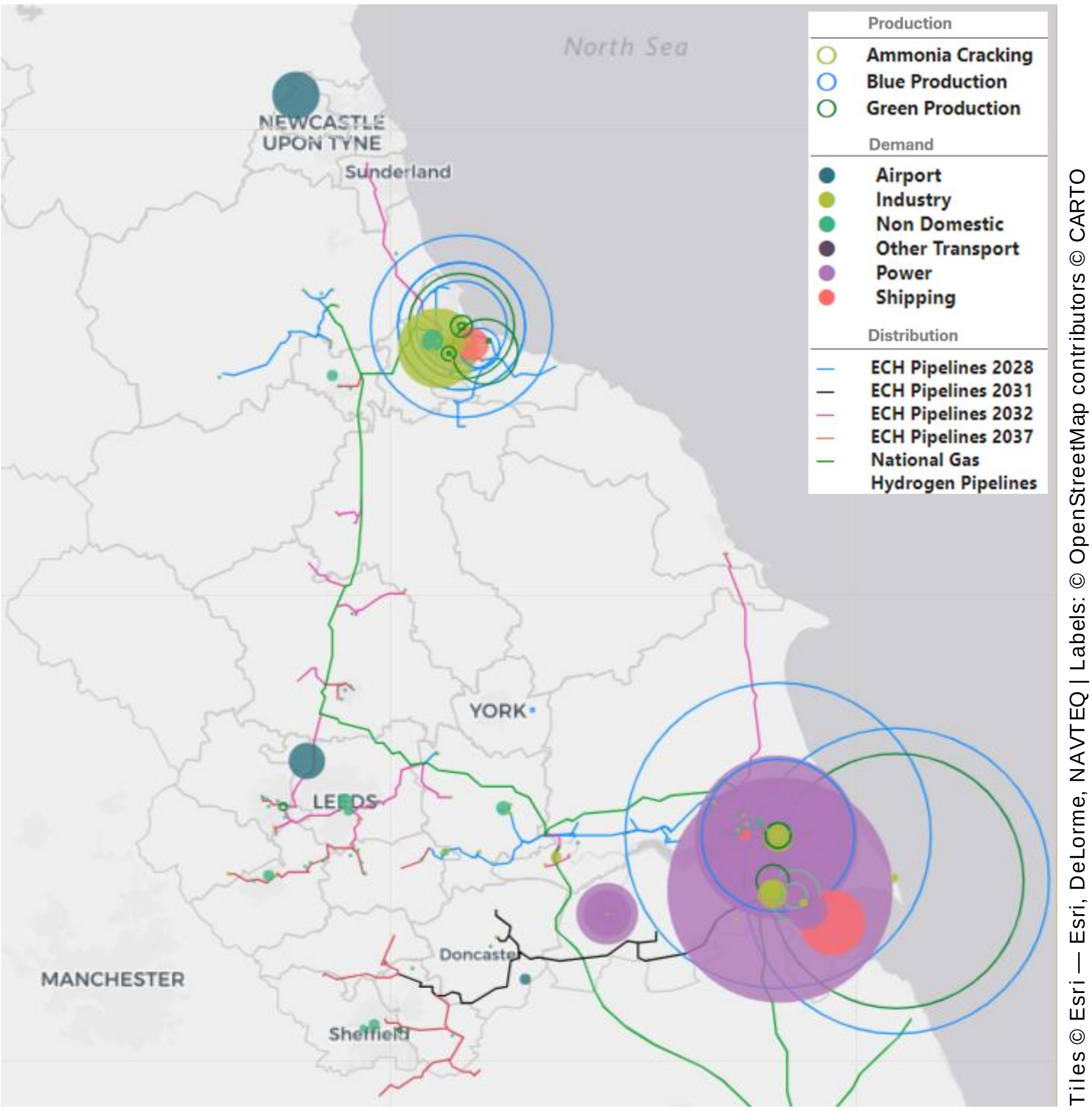

Figure 17 - Hydrogen supply and demand points in 2040

Figure 18 shows the 'final' snapshot of supply and demand in 2040, after all planned production and distribution projects are complete, and all sectors that will use hydrogen have switched from fossil fuels (in part, or in full).

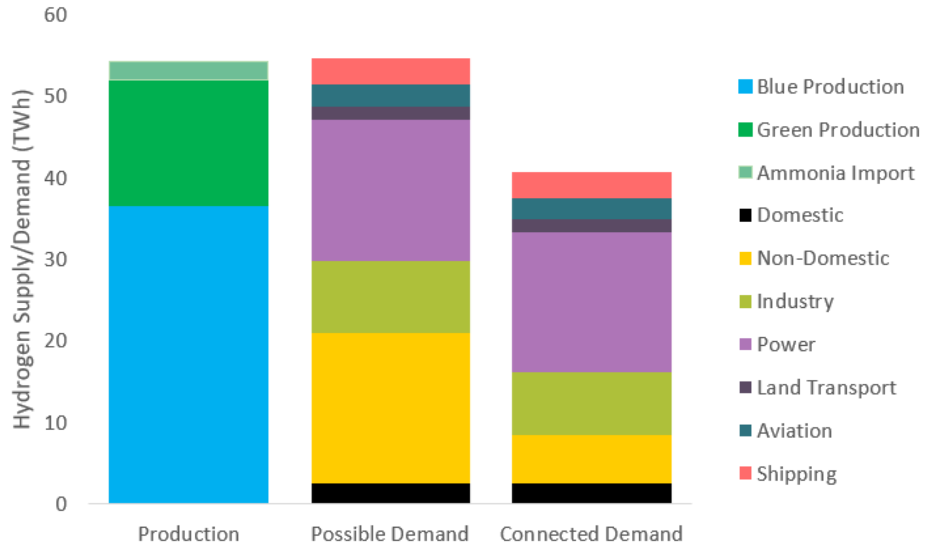

Figure 18 – Regional hydrogen balance in 2040

Production (+2TWh from 2032)

Two further phases of existing production plants (one electrolytic and one cracking ammonia) are expected to come online between 2033 and 2035, bringing the total hydrogen supply in the region to approximately 54 TWh per year. In this final snapshot, available supply continues to exceed the expected demand and is discussed further in Section 0.

Demand (+9TWh from 2032)

Connected demand increases by 30 % compared to 2032, driven by uptake of SAF at airports (Leeds Bradford and Newcastle) from 2035 and additional connections facilitated by ECH in the WYCA area. Demand at airports continues to grow to 2050, as the proportion of SAF increases and air travel grows.

Following this final extension of the planned distribution network some industrial sites, comprising around 1 TWh of annual demand, are still not connected to a supply point in the model (including the Port of Tyne). These are mostly single sites that do not meet the model threshold for connection, due to their distance from the hydrogen network.

4.1.6 Unsatisfied Demand

In this scenario the planned extent of ECH supplies almost all the major hydrogen demands in the Hub region. Some sites, however, remain unsupplied and using the methodology described in Appendix B, a small number of industrial sites as well as the Port of Tyne were identified as potential locations for local green hydrogen production. This additional production is expected to also supply a proportion of the local non-domestic demand as part of a ‘mini cluster’.

These locations and the estimated electrolysis capacity required are summarised in Table 5, and are shown overlaid on the Hub region map in Figure 19. The required electrolyser sizes are similar in scale to those awarded HAR1 funding and could potentially be supported by future HAR allocations.

Table 5 - Scenario 1: Additional Production Sites

Location & Lead Site	Mini-Cluster Annual Hydrogen Demand (GWh)	Required Electrolyser Capacity (MW)
Cudworth (Ardagh Glass)	180	25
Rotherham (Beatson Clark, Glass)	200	30
South Shields (Port of Tyne)	130	20

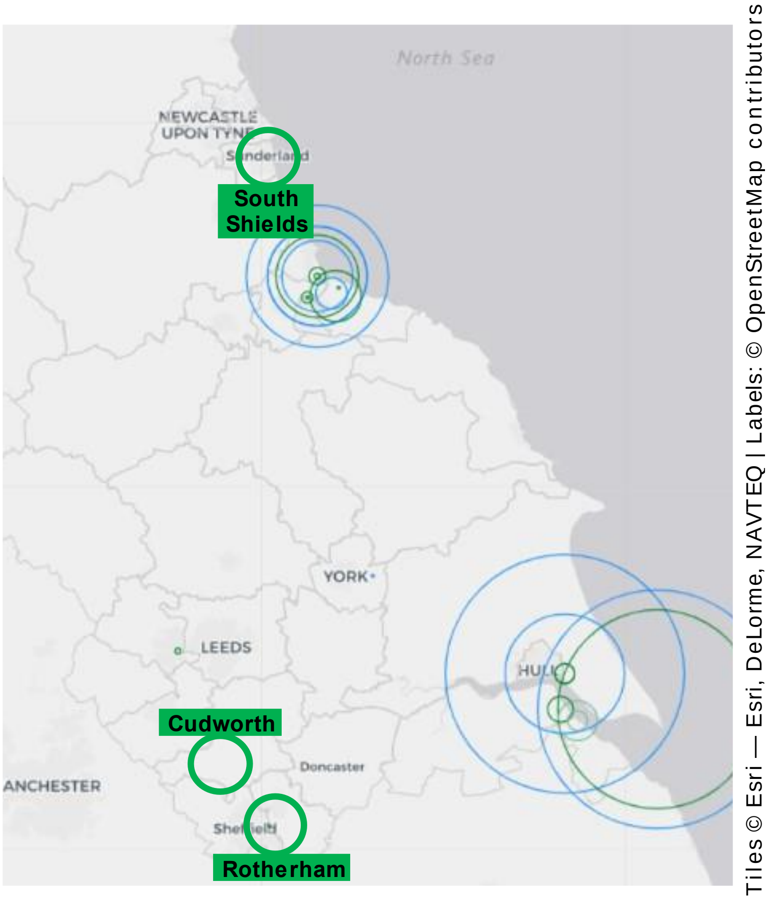

Figure 19 - Scenario 1: location of additional production

north east & yorkshire
NET ZERO HUB

4.1.7 Economic Analysis

Figure 20 shows the investment required in the Hub region for the modelled buildout of hydrogen assets and supported jobs from 2024 to 2040.

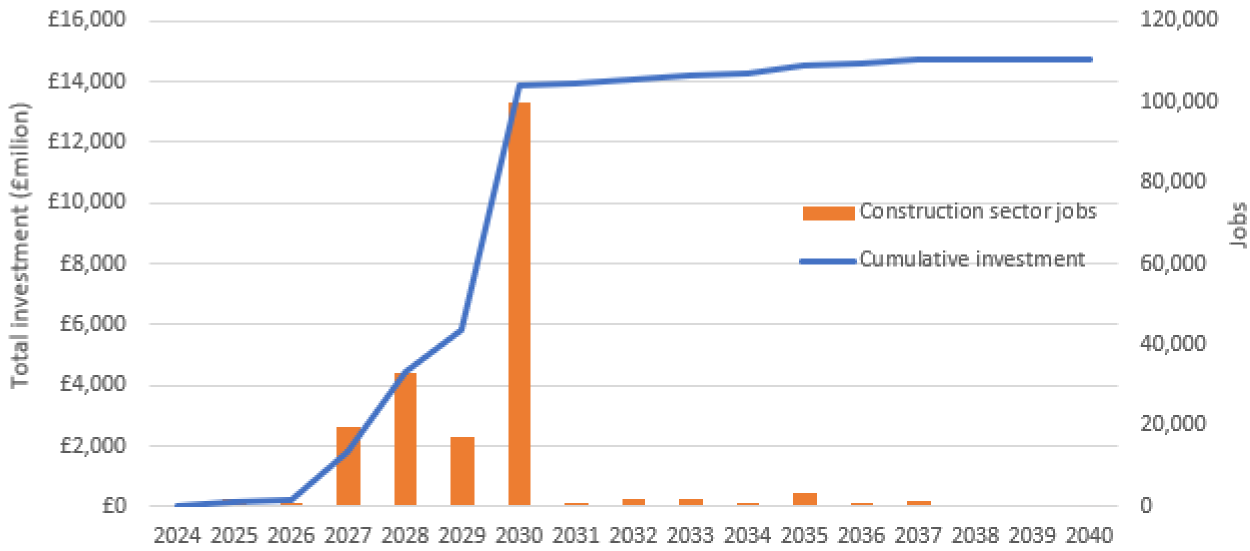

Figure 20 – Scenario 1: Investment required and job creation

As noted in Appendix C, the peak in 2030 is a result of modelling simplifications and is driven by 2030 being the planned operational date of several large production projects, as well as being when a number of end-users adopt hydrogen (and incur conversion costs). If we assume that the total investment shown for 2027-2030 can be spread evenly across this period of time, an average of approximately 40,000 direct and indirect jobs could be supported each year during this intense construction period. The number of jobs supported by further investment in hydrogen projects drops significantly after 2030, with only the construction of later ECH phases, smaller site conversions, and a few production projects expected.

A significant cumulative investment of £15 billion is required and Figure 21 shows how this is broken down between the different hydrogen sectors: the majority being for the hydrogen production facilities and the conversion/retrofit of end users. Within production, most investment is required for the blue and green plants in the Humber and Teesside clusters. Within conversion, most investment is required to convert existing power stations, with a smaller proportion required for industrial sites. The industrial investment is distributed across many individual sites, although a significant proportion of these are also located in, or near, the Humber and Teesside clusters. Investment in distribution pipelines is a smaller proportion of the total and is driven by Project Union and ECH. Whilst significant storage is planned, this is the smallest proportion of investment due to the lower capital cost of construction.

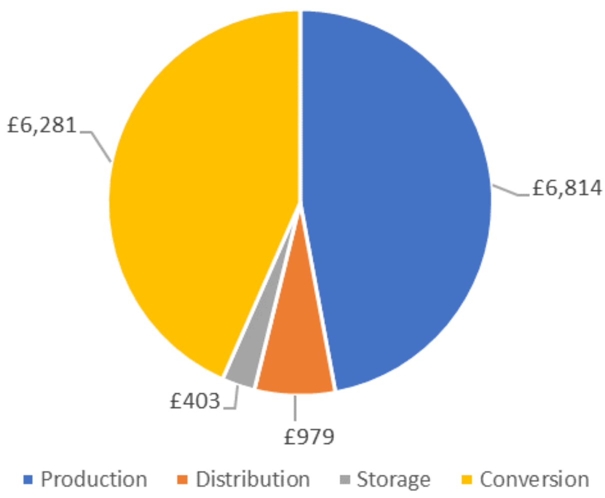

Figure 21 – Scenario 1: Breakdown of investment (£million) for hydrogen deployment

4.2 Scenario 2 – Reduced Production

The supply of low carbon hydrogen is dependent on the successful deployment and operation of blue and green production at scale. In the Hub region, blue hydrogen forms the majority (70%) of planned production capacity, concentrated in the Humber and Teesside clusters where there is access to the planned offshore CO_2 stores and natural gas infrastructure. Production is also dominated by a small number of large blue hydrogen projects, with the largest three comprising 80% of blue hydrogen production and 50% of total production.

Technical, economic or regulatory challenges could cause blue or green production projects to be delayed or cancelled, with a number of challenges noted in a recent PWC report[17]. To model a significant reduction in hydrogen supply in the Hub region, in this scenario it is assumed that three large blue projects do not go ahead, e.g. due to issues with CCUS technology, upstream/fugitive emissions, costs or planning consent.

Results are presented for 2040, after all planned projects are complete, to show the overall difference in future development compared to Scenario 1.

[17] Navigating the hydrogen ecosystem, what's preventing progress?, PWC, April 2024, Link

4.2.1 2040

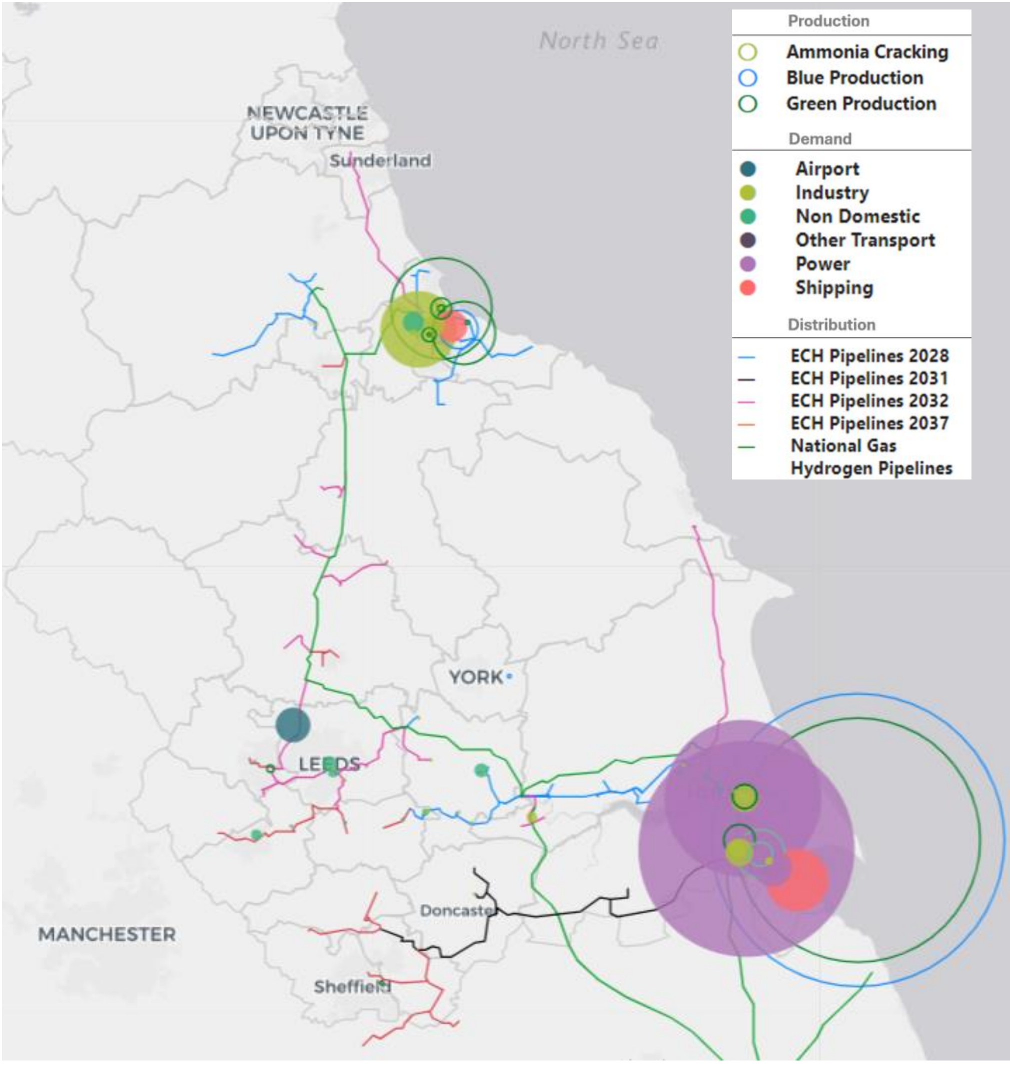

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Figure 22 - Scenario 2: Regional map in 2040

Figure 22 shows the regional hydrogen map. In comparison to Figure 17 from Scenario 1, this highlights the reduction in demands that are supplied outside of the Humber and Teesside clusters despite the full ECH pipeline network being available. The model prioritises connecting the most favourable sites first (defined as those with the largest demand vs. distance connection metric), continuing until there is no further spare production capacity. This results in the majority of hydrogen being consumed by sites in the clusters (which are large and close to the network), particularly by the power sector, leaving little 'spare' to supply demands in the wider Hub region. Sites not supplied in this scenario include the Keadby power station, Newcastle airport and a range of inland industrial sites.

Figure 23 shows the balance of production and demand in this scenario. On the production side this shows a reversal of the situation in Scenario 1 with green hydrogen production (largely in the Teesside and Humber clusters) now forming the majority of supply. As noted above, only a proportion of demand in the aviation, power and industrial sectors can be supplied by the local production and, for all sectors, the annual consumption is 12 TWh lower than in Scenario 1. It is also assumed in this scenario that supplying domestic demands would not be prioritised.

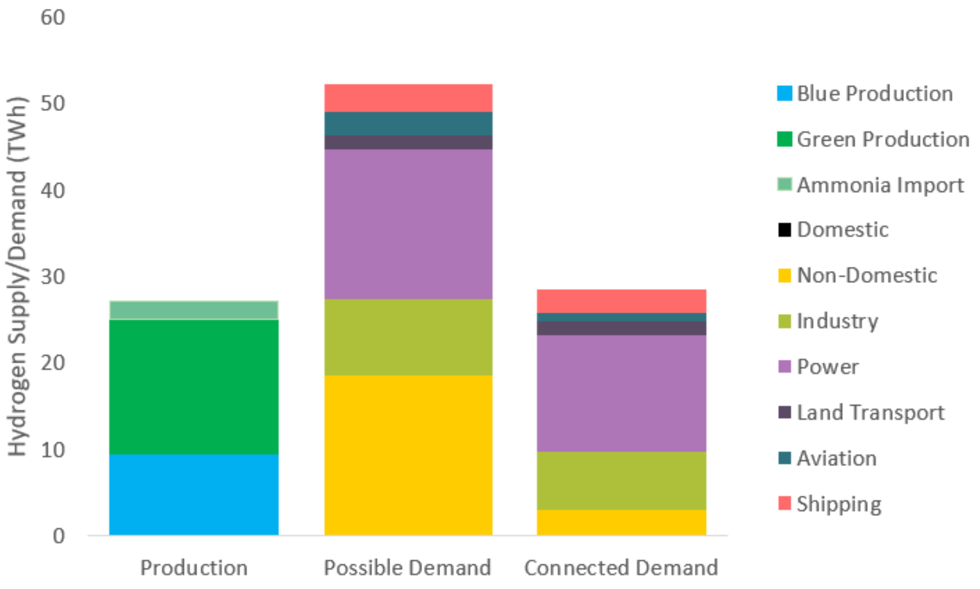

Figure 23 – Scenario 2: Balance in 2040

Results from this scenario highlight that:

- With no spare capacity in the Hub region, additional delays or cancellations of other production projects would lead to a further reduction in what could be supplied.
- ECH is intended to distribute hydrogen production from the clusters, where the majority is located, further inland. Limited production could therefore affect the case for building out ECH, with Figure 22 showing the limited number of sites along the proposed pipeline routes that would be supplied.

To mitigate the shortfall in production, hydrogen or hydrogen-based fuels could be imported from outside the Hub region if there is sufficient capacity elsewhere and if this hydrogen is available at a reasonable cost. Alternatively, a reduced supply may lead to the prioritisation of demands.

Of the sectors considered in this study, the use of hydrogen for baseload power (as is proposed for the part-conversion of Immingham and Saltend CHP plants) is considered to be the lowest priority[18] and was removed from the model in a sensitivity study. The removal of these two sites reduces consumption in the power sector by two thirds and Figure 24 shows the overall supply/demand balance. In this case, all hydrogen demands except domestic across the Hub region could be met which highlights the degree of oversupply for the region (discussed further in Section 5) and the significant impact of the Saltend and Immingham sites on demand in the region.

[18] FES and CCC modelling do not show a role for hydrogen in baseload generation. The low overall efficiency of hydrogen production > electricity generation means that it is only considered for dispatchable generation from stored hydrogen.

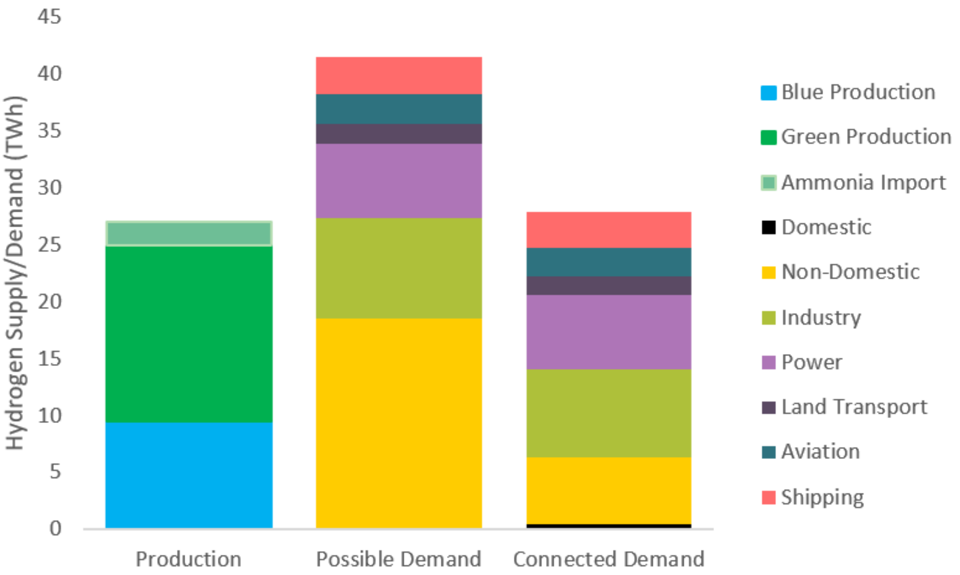

Figure 24 – Scenario 2: Revised supply and demand

4.2.2 Unsatisfied Demand

If baseload power generation is removed from the model, the supplied sites (excluding the power sector) are the same as in Scenario 1, and the same locations for additional green production can therefore be considered (see Section 4.1.6).

As noted above, domestic demand is not prioritised in this scenario and an alternate hydrogen supply or decarbonisation pathway would be required. Further analysis would be needed to refine the top-down assumption used and understand which homes could not feasibly use an alternative (such as a heat pump), to assess which of the options discussed in Section 5.2.5 is most appropriate.

4.2.3 Economic Analysis

Figure 25 shows the investment required in the Hub region for the modelled buildout of hydrogen assets and supported jobs from 2024 to 2040.

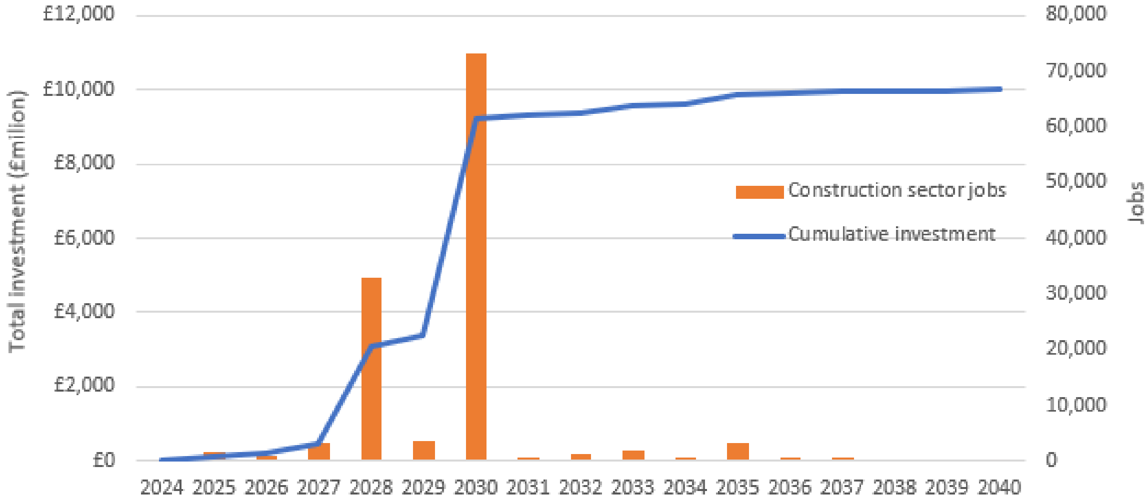

Figure 25 – Scenario 2: Investment required and job creation

With the removal of large blue production plants compared to Scenario 1, cumulative investment is estimated at £10 billion with approximately 28,000 jobs supported each year from 2027-2030. This represents a significant reduction during this period and Figure 21 shows the breakdown of investment which echoes the clear reduction in the investment required for hydrogen production assets.

Total investment would be approximately £1 billion lower in 2030 in the event of Saltend and Immingham power stations not being converted, offset by a small additional cost of converting smaller industrial sites which could then be supplied.

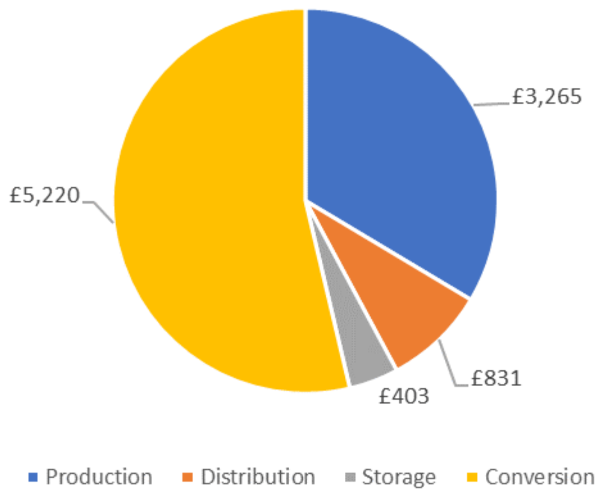

Figure 26 – Scenario 2: Breakdown of investment (£ million) for hydrogen deployment

4.3 Scenario 3 – Reduced Demand

The hydrogen uptake factors for each sector used in the model (see Appendix B) represent a current best-estimate for the Hub region but include some assumptions around the availability and cost of hydrogen to determine its role relative to other decarbonisation pathways. This scenario considers the case where hydrogen uptake is lower in some sectors; a potential result of either a high unit cost, development/cost reduction of alternative decarbonisation technologies, or the delayed development/availability of technology for hydrogen use. A lower overall hydrogen uptake broadly aligns with the FES 'Consumer Transformation' scenario and is judged more likely than the higher-hydrogen 'System Transformation' scenario, where a significant proportion of the increased hydrogen consumption is driven by space heating and land transport, in which, as noted in Section 3.2, significant uptake is not currently expected in the UK.

Overall, this scenario restricts the use of hydrogen to sectors where hydrogen is seen as essential to their decarbonisation and, therefore, act as a minimum expected demand in the region. The following sectors are assumed to require hydrogen (at the same uptake factors as used in other scenarios):

- Aviation
- Shipping
- Land transport
- Industry
    - Chemical industry
    - Other mineral industries (i.e. glass manufacturing)
    - Processing and distribution of petroleum products
- Power (peaking plants only)

Domestic, non-domestic, baseload power generation and other industries are assumed to utilise alternative decarbonisation pathways in this scenario.

Results are presented for 2040, after all planned projects are complete, to show the overall difference in future development compared to Scenario 1.

4.3.1 2040

Figure 27 shows the regional hydrogen map with a reduced uptake of hydrogen. Compared to Scenario 1, the reduction in non-domestic and smaller industrial sites requiring hydrogen is noticeable across the inland Hub region, whilst the Humber and Teesside clusters show a smaller difference (albeit with the notable removal of the Saltend and Immingham baseload power stations).

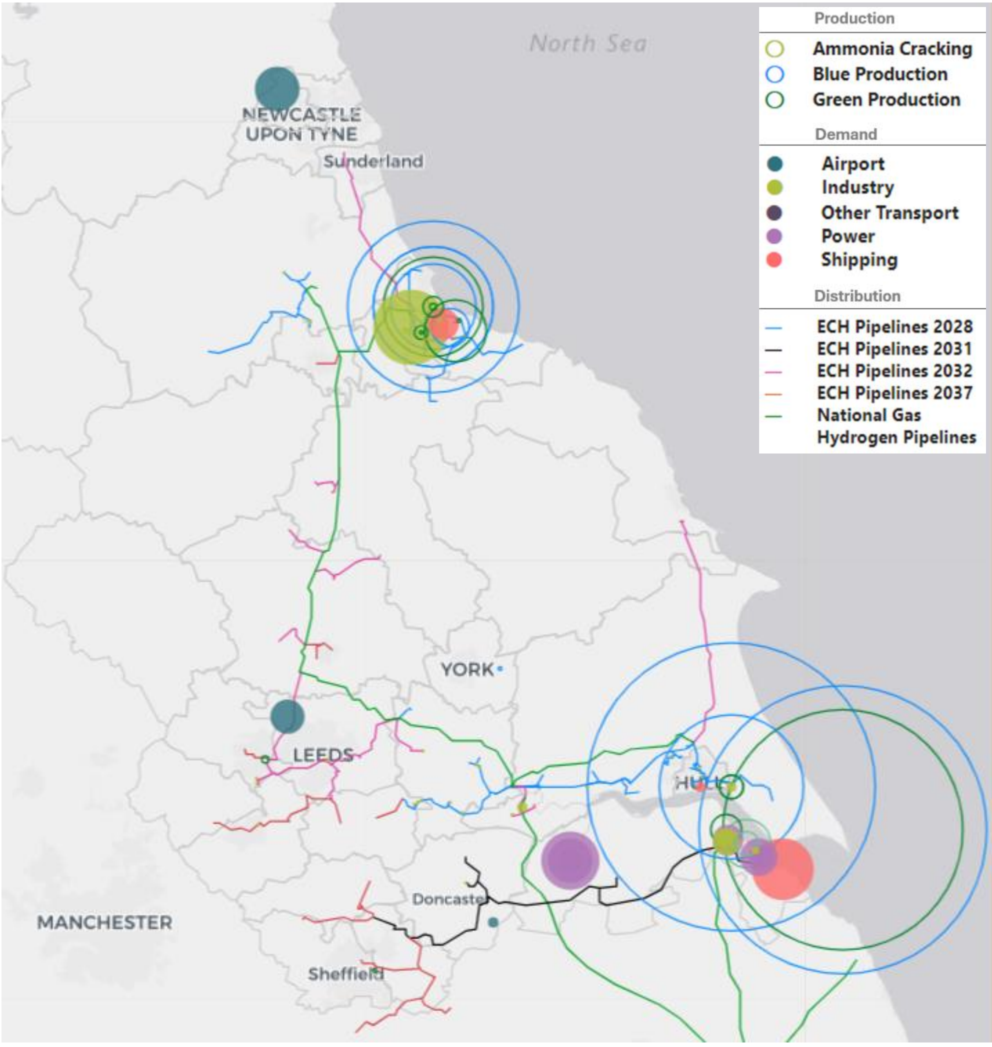

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Figure 27 - Connected hydrogen demands

Figure 28 shows the supply and demand balance. The connected demand of 19 TWh across the five sectors represents a significant 50 % reduction compared to Scenario 1. There are large reductions in the power and industry sectors, however, this scenario also demonstrates a significant 'minimum' hydrogen demand in the Hub region. Although not modelled, as it is in a scenario with lower overall hydrogen consumption, the scale of production projects planned may also be reduced. There is clearly a significant surplus of hydrogen in this scenario if all planned projects were to go ahead: this would require a greater export of hydrogen from the region, as discussed further in Section 5.

In this scenario, 15 % of the total demand in the Hub region requires the ECH network to connect. This proportion is similar to the other scenarios, however, because of the reduction of total connected demand in this scenario, the annual amount of consumption requiring ECH is significantly reduced. Further analysis is required, but this would clearly impact the business case and feasible extent of the network, with local production potentially required for remaining sites (see below).

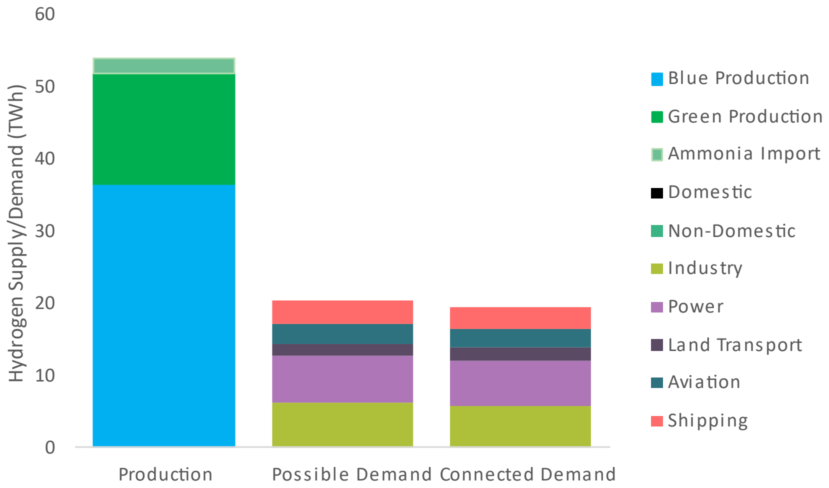


Figure 28 - Scenario 3: Supply and demand balance

4.3.2 Unsatisfied Demand

With the ECH network, locations for additional production are the same as in Scenario 1 (see Section 4.1.6) as these involve industries that would still require hydrogen. The electrolyser capacity would, however, be reduced, with fewer 'secondary' sites in the vicinity (such as non-domestic) that would be assumed to require hydrogen. If the ECH network is reduced in scope, locations for additional production would be similar to Scenario 4, but restricted to those sectors that would still require hydrogen.

4.3.3 Economic Analysis

Figure 29 shows the investment required in the Hub region for the modelled buildout of hydrogen assets and supported jobs from 2024 to 2040.

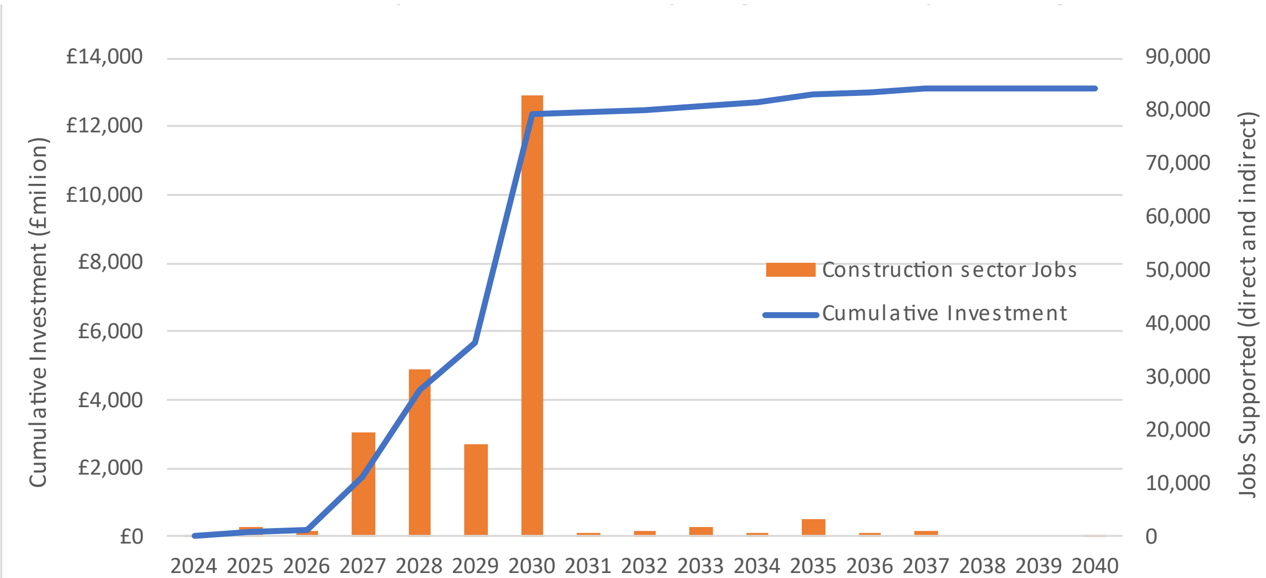


Figure 29 – Scenario 3: Investment required and job creation

Cumulative investment in this scenario is approximately £13 billion, the reduction in conversion of some sites (relative to Scenario 1) makes a relatively small difference as this remains dominated by the cost of converting power stations (for peaking operation). Figure 30 shows the breakdown, with a greater proportion of investment required for hydrogen production assets. Scenario 2 (see Section 4.2.3) shows that there could be a further reduction in investment of approximately £4 billion if production projects were to be scaled back significantly (e.g. to more closely match demand from offtakers in the Hub region).

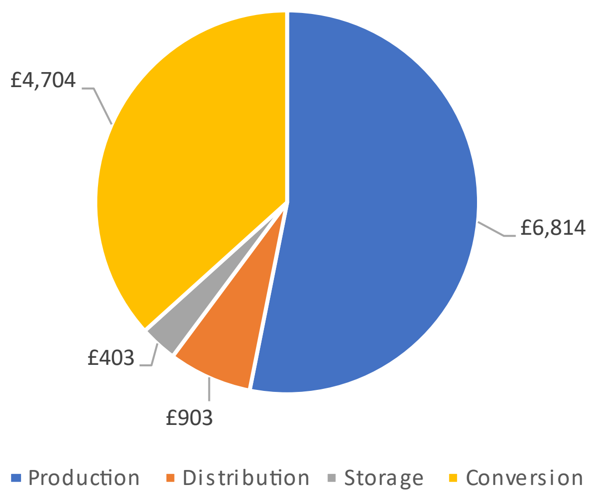


Figure 30 – Scenario 3: Breakdown of investment (£million) for hydrogen deployment

4.4 Scenario 4 – Reduced Distribution

As noted in Appendix B, it is not feasible within the model to independently simulate the development of transmission-level pipelines given the complexity of the routing and demands, so the model incorporates planned infrastructure such as ECH and the section of Project Union. These pipelines, as planned, would already provide a relatively extensive pipeline network for hydrogen in the region that connects the majority of large production and demand sites as shown in Scenario 1.

There is currently expected to be limited deployment of large hydrogen assets (such as significant production or storage sites) in the Hub region outside of the clusters. These would require their own pipeline connections and would therefore, if present, potentially support connections within the region as an alternative to ECH.

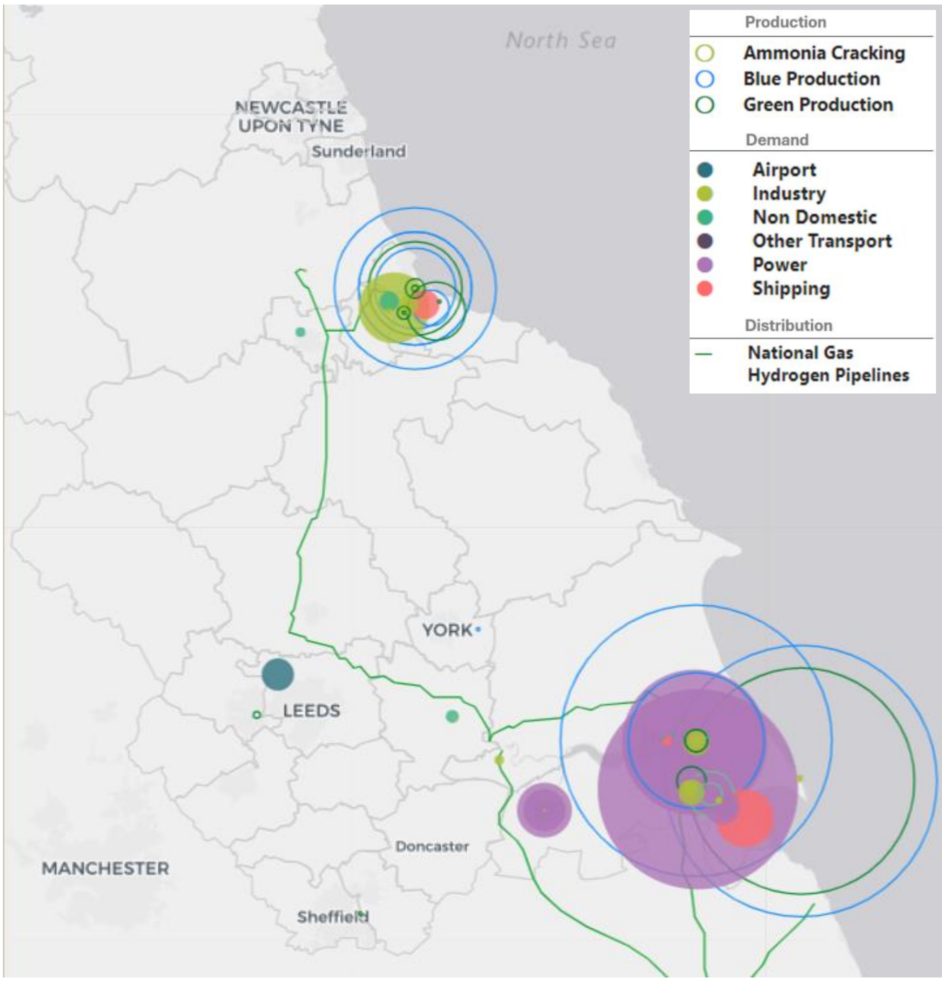
The phases of ECH are key projects that will enable hydrogen supply to the wider region. The business case for each phase is dependent on the hydrogen uptake from a relatively small number of industrial sites that comprise the majority of non-cluster demand (unless further demand is unlocked by higher uptake than has been assumed for domestic/non-domestic sites).

This scenario considers a future where Project Union (with national backing and significance) goes ahead, but that subsequent ECH phases do not. This could be due to impacts on the business case such as reduced hydrogen production in the industrial clusters (see Scenario 2), or a lack of commitment from offtakers driven by high price or lack of certainty on the timeline for hydrogen availability.

Results are presented for 2040, after all planned projects are complete, to show the overall difference in future development compared to Scenario 1.

4.4.1 2040

Figure 22 shows the regional hydrogen map in 2040 when ECH is not constructed.



Tiles © Esri — Esri, DeLorme, NAVTEQ | Labels: © OpenStreetMap contributors © CARTO

Figure 31 - Connected hydrogen demands without ECH

It is clear that few potential demands outside of the Humber and Teesside clusters are supplied in this scenario, limited to those which are relatively close to the Project Union pipeline or other production sites. Although using a simplified approach, the model shows that single sites or clusters in the wider Hub region are not likely to have a sufficient hydrogen demand, and are too dispersed, to drive organic growth of a hydrogen network that would connect them. Although Newcastle Airport is shown as unconnected, this is expected to use SAF, for which a pipeline supply is not required, and so it is included in the results below.

Figure 32 shows the balance of production and demand.

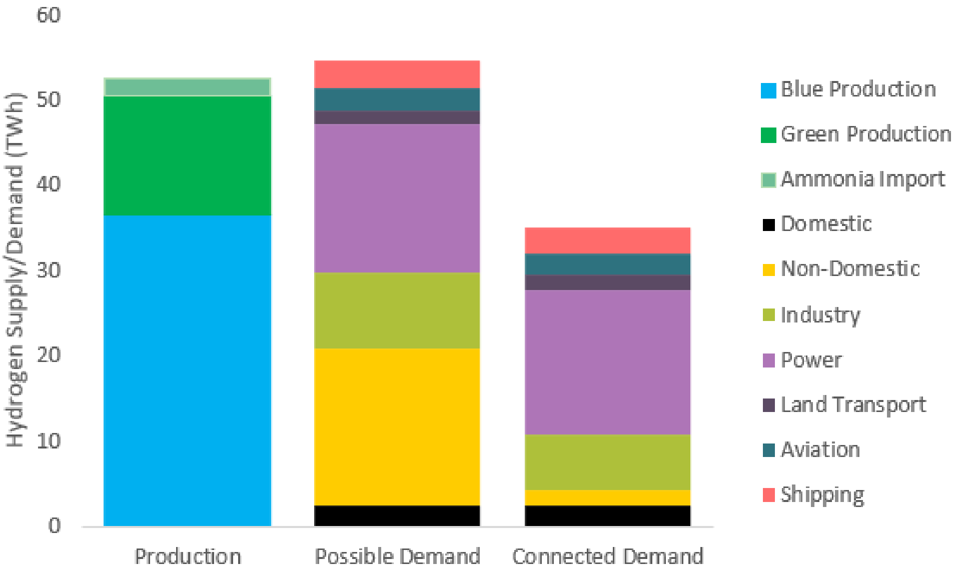


Figure 32 - Scenario 4: Supply demand

In comparison with Scenario 1, the overall connected demand is approximately 13 % lower in this scenario which is due to industrial and non-domestic sites in the wider Hub region not being connected. This highlights the weighting of hydrogen demand in the Hub region towards the industrial clusters and, whilst the non-cluster demand remains significant (5 TWh), as noted above, this is relatively dispersed and would require an additional 1,000 km of ECH pipeline to be constructed or repurposed in order to be supplied. The marginal demand and pipeline requirements of each ECH phase have not been assessed at this stage.

4.4.2 Unsatisfied Demand

If ECH is not constructed, a wide range of smaller sites across the region would have no access to a pipeline hydrogen supply. Alternative approaches for these sites to obtain hydrogen (or an alternative) are discussed in Section 4.4.3 and Section 5.2.5.

For this scenario an assessment of potential locations for green hydrogen production shows several additional mini clusters could be considered, in addition to those identified in Scenario 1 (see Table 6 and Figure 33). The additional sites are mostly located in the West and South Yorkshire areas where there are a number of glass or chemical plants. The total additional production capacity required in this scenario would be approximately 250MW, with an average electrolyser size of 25MW which is at a scale that could be supported by HAR funding.

Table 6 - Scenario 1: Additional Production Sites

Location & Lead Site	Mini-Cluster Annual Hydrogen Demand (GWh)	Required Electrolyser Capacity (MW)
Cudworth (Ardagh Glass)	180	25
Rotherham (Beatson Clark, Glass)	200	30
South Shields (Port of Tyne)	130	20
Newton Aycliffe (Travik Chemicals)	80	11
Doncaster (Ardagh Glass)	240	34
Huddersfield (Lubrizol, Chemicals)	200	29
Bradford (Solenis, Chemicals)	240	34
Leeds (Verallia, Glass)	210	30
Eggborough (St Gobain, Glass)	60	9
Knottingley (Ardagh Glass)	220	32

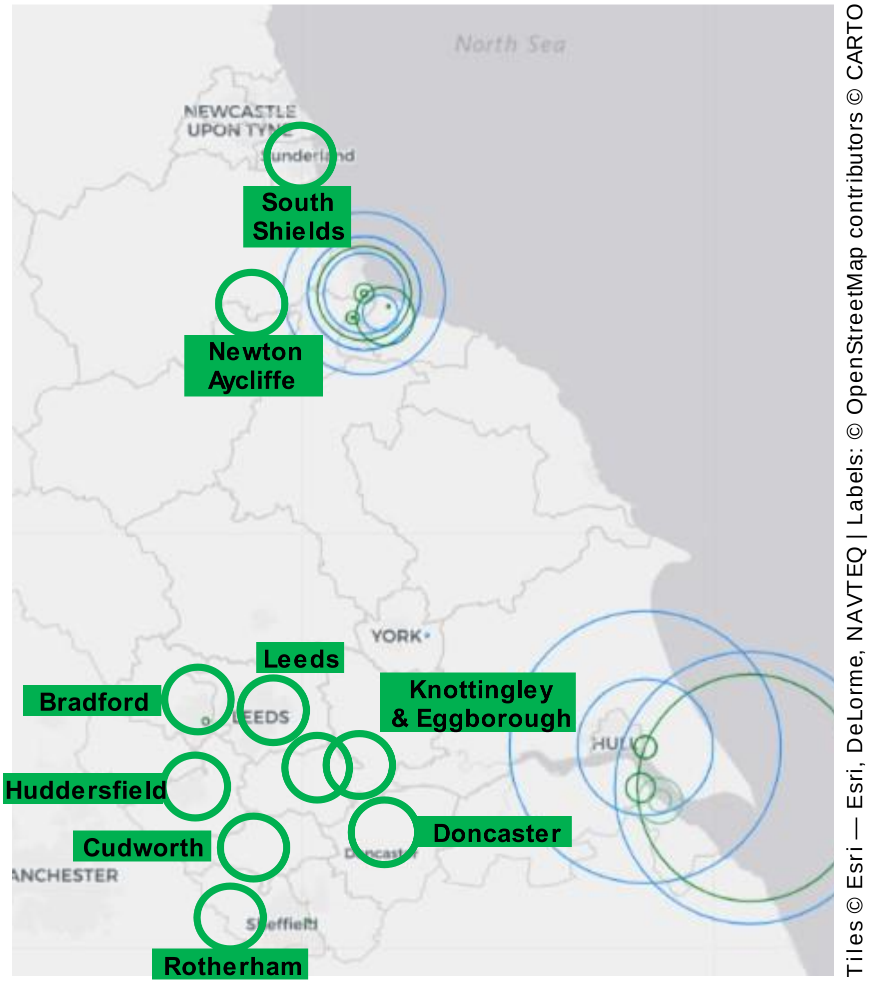


Figure 33 - Scenario 4: potential location of additional production sites

4.4.3 Economic Analysis

Figure 34 shows the investment required in the Hub region for the modelled buildout of hydrogen assets and supported jobs from 2024 to 2040.

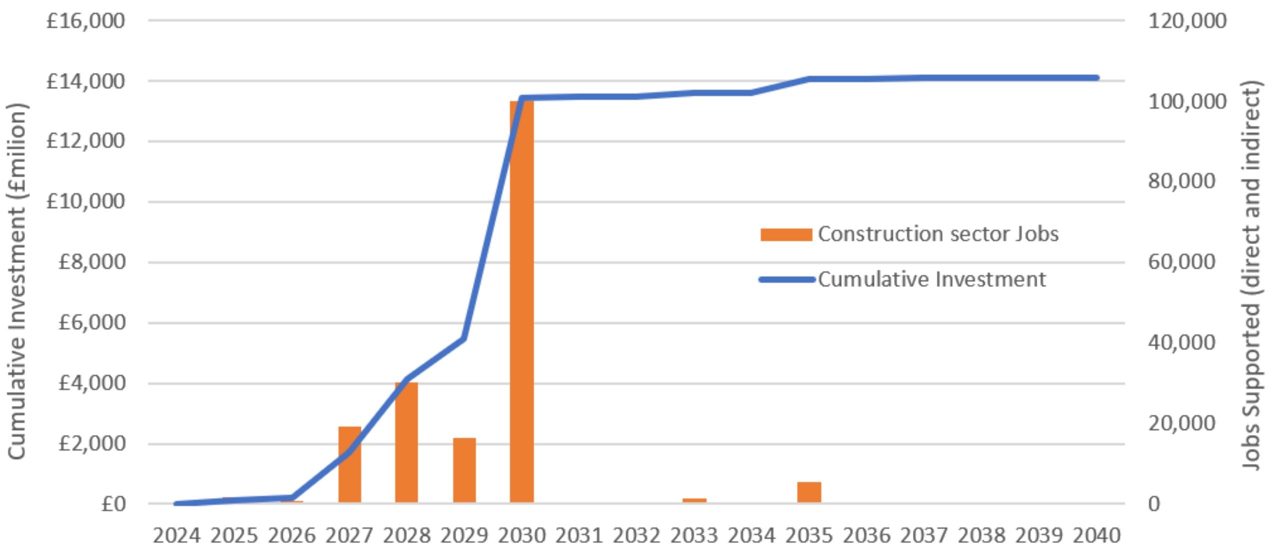


Figure 34 – Scenario 4: Investment required and job creation

This scenario shows that there is a relatively small reduction in total investment compared to Scenario 1 if ECH is not constructed. The installation of distribution pipeline and conversion of smaller industrial sites represent smaller proportions of the overall cost (see Figure 35) and are also partially offset by additional localised green production that is assumed to be required. This scenario highlights the significant proportion of overall investment driven by hydrogen assets in and around the Humber and Teesside industrial clusters.

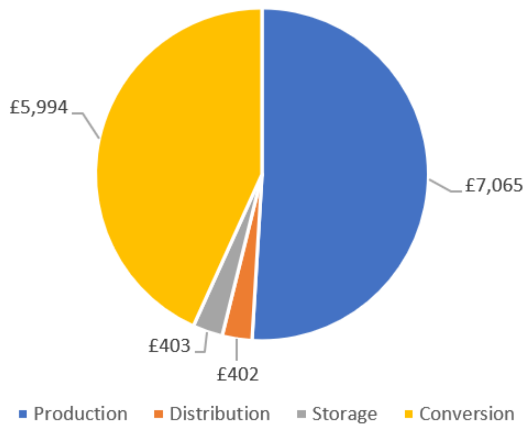


Figure 35 – Scenario 3: Breakdown of total investment (£ million) for hydrogen deployment

5 HYDROGEN ROADMAP

This section discusses the results from Section 4, identifying some key factors and dependencies for hydrogen development across the assessed scenarios and summarising these into a roadmap for Hub region.

5.1 Scenario Summary

Table 7 shows a summary of key metrics from the assessed scenarios. This highlights the significant impact that could occur from changes or issues with individual technologies or projects, as well as the large potential variance between scenarios.

Table 7 - Scenario Summary for 2040

	Hydrogen Production (planned)	Connected Demand	Total Pipeline Distance	Potential for local green hydrogen production	Investment (£ billion)
Scenario 1 (Planned Projects)	54 TWh: • 37 blue • 15 green • 2 ammonia cracking	41 TWh	1,700 km	70 MW	£14.7
Scenario 2 (Reduced Production)	27 TWh • 9.5 blue • 15 green • 2 ammonia cracking	27 TWh	1,500 km	70 MW	£10.0
Scenario 3 (Reduced Demand)	54 TWh: • 37 blue • 15 green • 2 ammonia cracking	19 TWh	1,600 km	70-250 MW	£13.0
Scenario 4 (Reduced Distribution)	54 TWh: • 37 blue • 15 green • 2 ammonia cracking	35 TWh	630 km	250 MW	£13.9

Figure 36 to Figure 39 show the evolution of hydrogen supply, demand and distribution pipeline in each of the assessed scenarios.

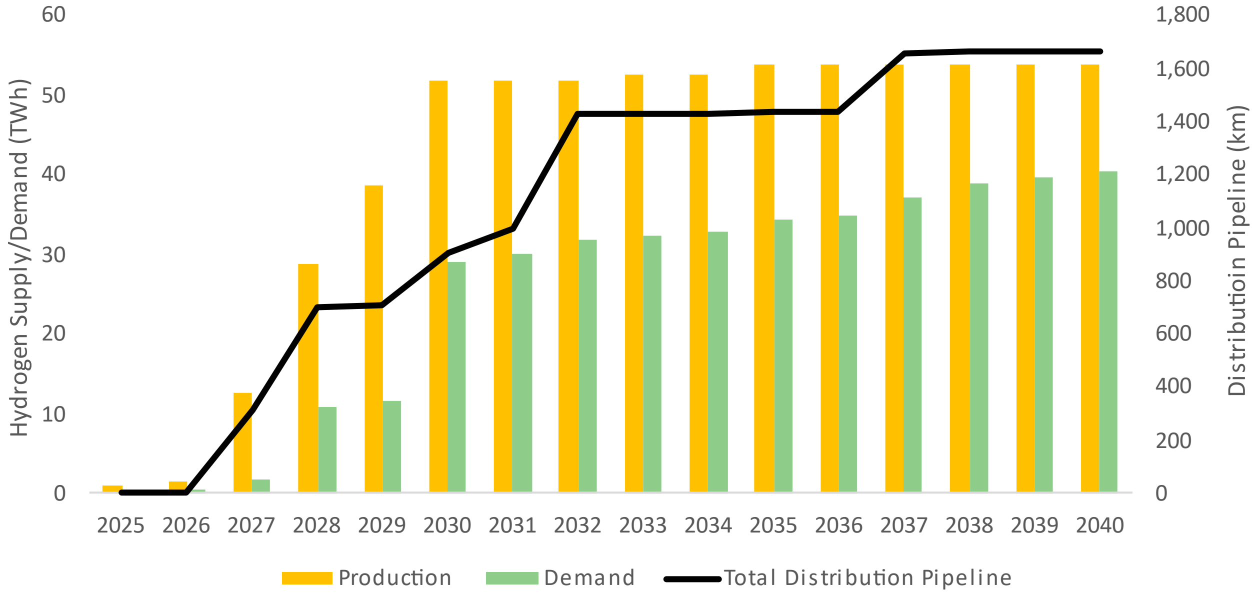


Figure 36 – Scenario 1 (Planned Projects) - Evolution of hydrogen supply and demand

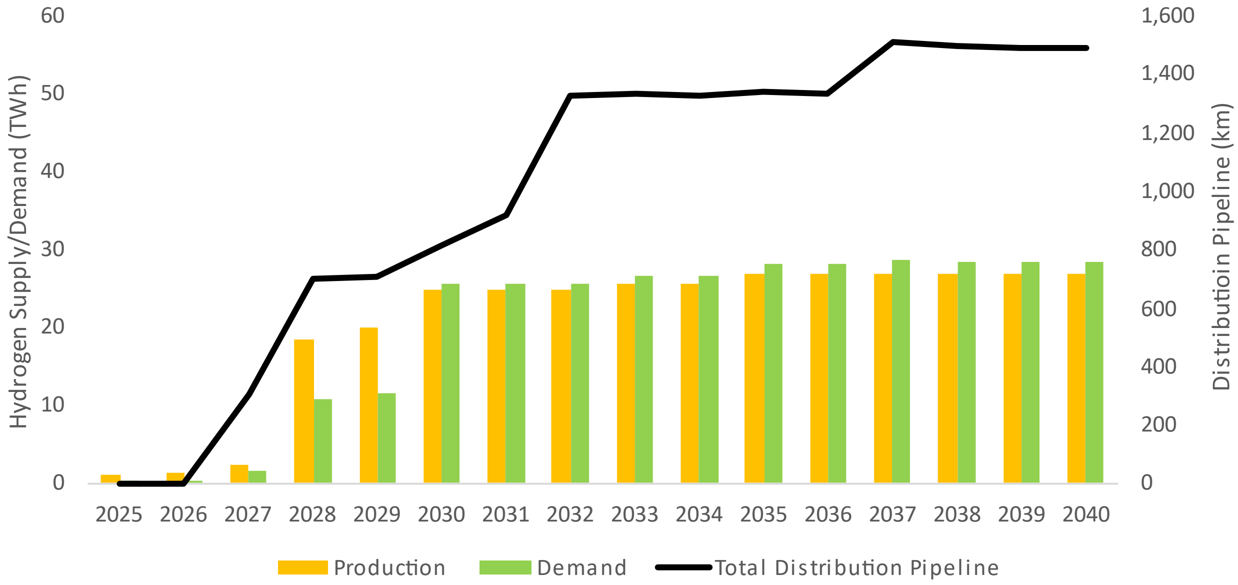


Figure 37 – Scenario 2 (Reduced Production): Evolution of hydrogen supply and demand

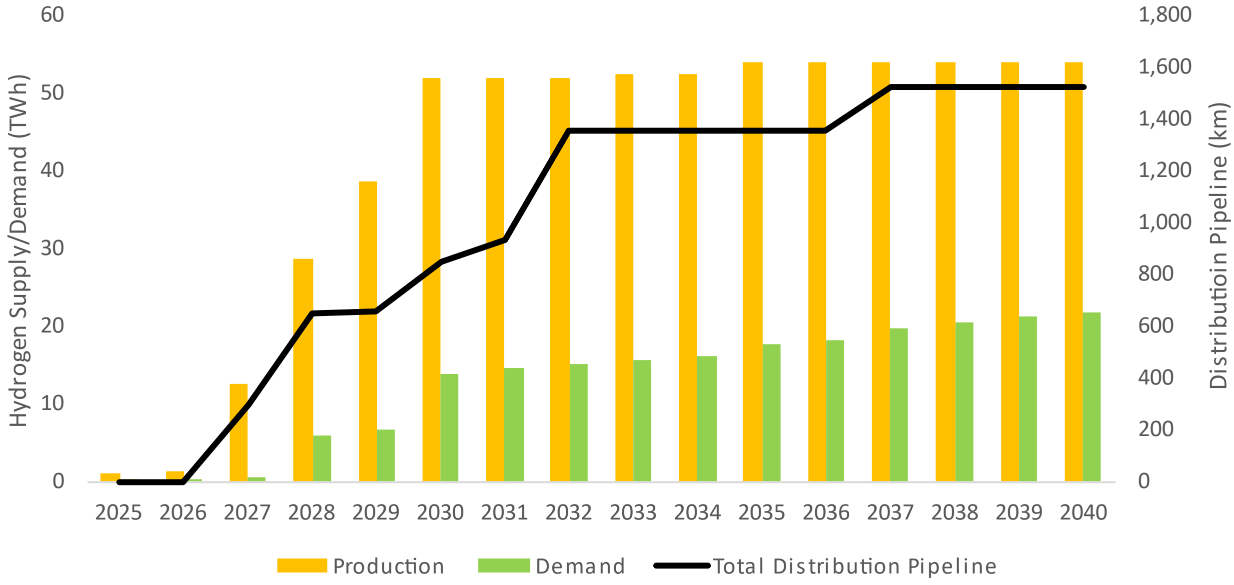


Figure 38 – Scenario 3 (Reduced Demand): Evolution of hydrogen supply and demand

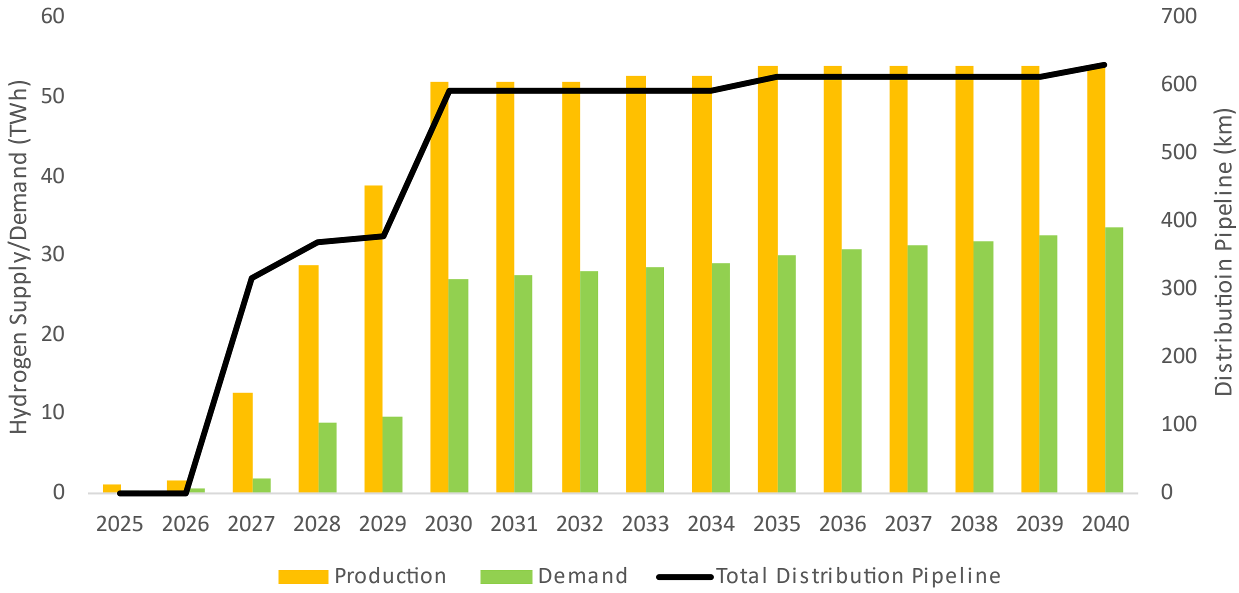


Figure 39 – Scenario 4 (Reduced Distribution): Evolution of hydrogen supply and demand

5.2 Observations and Common Factors

5.2.1 Dependence on specific projects

The assessed scenarios show that hydrogen development in the Hub region will be influenced by outcomes of a relatively small number of projects or sectors:

- Some individual sites (power stations and airports) are expected to account for a significant proportion of overall hydrogen demand, decisions on if/how hydrogen is used at these sites will therefore have an influence on local distribution and offtake agreements, particularly if production is constrained.
- Hydrogen production is dominated by a small number of large projects, with the three largest blue production plants accounting for around 50% of planned production.
- The model assumes that a connection to the hydrogen pipeline network is required for viable supply in most sectors. This places a reliance on Project Union and particularly ECH, which is the only currently planned project that would provide hydrogen for sites in the wider Hub region. Alternative options for hydrogen supply are discussed in Section 5.2.5.

These dependencies mean that changes in these projects or sectors will likely have a significant impact on hydrogen development in the Hub region and that relevant stakeholders should be part of the hydrogen working group (see Section 7).

Although not assessed in this study, projects relating to supporting infrastructure such as renewable generation, grid connections, and CO_2 storage are also critical for hydrogen assets to become operational.

5.2.2 Planned rate of development from 2025-2030

As shown in Table 14 and in the modelled buildout of assets, approximately 8 GW of hydrogen production, Project Union, the first phase of ECH, and the Aldbrough storage facility are currently planned to be operational by 2030. This would require an intense period of construction (largely focussed on the Humber and Teesside clusters) over a five-year period and create tens of thousands of jobs.

If achieved, this would increase annual low carbon hydrogen production in the region from near zero to 54 TWh within this period, providing a significant proportion of the 10 GW government production target. As noted in Section 1.4.1, the viability of each project has not been assessed in this study, however, given the significant demands this period of construction would place on the local workforce, supply chain and supporting infrastructure, extensive coordination between stakeholders will be required.

Step changes in hydrogen demand are shown in the modelled results, although as noted previously, actual end-user conversion would be expected to take place more gradually.

5.2.3 Development after 2032

Of the planned hydrogen asset development, the majority is currently expected to be complete by the early 2030s, with only the final buildout of the ECH network taking place until 2037. The development of some current projects may be delayed into the 2030s or cancelled:

- Planned projects may have their scope revised – a number have changed in capacity, operational date or owner since being originally announced.
- Planned projects may encounter issues in design, planning and construction, or need to align with other dependencies such as offtakers, funding or supporting infrastructure.

Plans for hydrogen development more than five years ahead are inevitably limited due to the current uncertainty. As projects develop and the actual development and operation costs become clear, plans can be made with greater confidence. New projects are also expected in the Hub region:

- Favourable conditions in the Hub region (CO_2 storage points, offshore wind connections and a specialised workforce), particularly in the Humber and Teesside clusters, are likely to encourage additional production plants to be constructed, as well as processing/export facilities for hydrogen fuels and carriers.
- The Hub region may attract additional industry to utilise the available hydrogen (see below), which could then incentivise further growth in supply: a positive feedback loop.
- Additional hydrogen storage projects are expected to be developed (see Section 5.2.6).

5.2.4 Excess Production

The model shows that annual hydrogen production from the planned projects is consistently expected to exceed consumption in the Hub region by a significant margin. As noted previously, the model does not dynamically adjust supply and so this represents the most optimistic view if all projects were to go ahead.

Clearly the industrial clusters are favourable locations for large scale blue and green hydrogen production in the UK, so it is not surprising that a number of large plants are planned. The degree to which each project is dependent on government funding, specific offtakers, supporting infrastructure etc. has not been assessed in this study but some change in the scope of projects is expected as designs and business cases are developed. This could also include cancellation, although the analysis shows that there is likely to still be excess production capacity unless several significant projects are not taken forward. Routes for this 'excess' hydrogen could include:

- Export – either via the Project Union NTS to other parts of the UK, or via ports to other UK/international locations (as pure hydrogen, hydrogen-based fuel or a hydrogen carrier). The scope for this route would be dependent on the production capacity and cost of hydrogen produced elsewhere in the UK or abroad.

- Additional local demand – the availability of hydrogen may incentivise businesses to locate new facilities or expand existing ones in the region
- Storage – for use in future power generation to balance long duration lulls in renewable output.
- Blending into natural gas supply – although this is to be considered a ‘last resort’ offtaker and is likely to be supported only as a transitional measure in certain cases[19].

5.2.5 Unsatisfied demand

The hydrogen distribution network, both planned and from organic growth, does not reach all potential hydrogen consumers although the extent of this varies by scenario. For sites that are not found to be connected, the following alternatives for hydrogen supply could be considered:

- Paying a higher connection cost to extend a hydrogen pipeline to the site (beyond what would normally be considered economic).
- Relying on future technical change, economic incentives or other nearby users connecting to reduce the overall cost of a pipeline connection.
- If hydrogen is blended into the wider natural gas supply, extracting pure hydrogen from an existing gas supply via deblending.
- Obtaining hydrogen from road/rail transport (although more flexible, this will have a higher unit cost than a pipeline and be limited in the volume that can be supplied)
- Relocating the site closer to a hydrogen supply or other source of low carbon energy.
- Producing green hydrogen onsite, or locally as part of a ‘mini cluster’.

If a hydrogen supply is not readily available via pipeline, then the cost of a hydrogen pathway for decarbonisation, requiring one of the options listed above, is likely to increase (potentially significantly). The hydrogen uptake factors used in the model include some implicit assumptions that hydrogen is readily available and at a reasonable cost to consumers. As the cost of a hydrogen pathway increases, this will likely result in a reduced number of sites where it remains the most cost-effective decarbonisation pathway (compared to electrification, biofuels, CCUS, etc.).

In this study, local production of green hydrogen has been assessed for sites with no modelled pipeline connection and with fewer alternative decarbonisation pathways. The identified locations are not exhaustive, but show that several ‘mini clusters’, based around small-medium size electrolysers, could be considered in the Hub region, increasing in number if some or all of ECH is not progressed.

There is also the possibility that some sites may prefer to install their own hydrogen production, even if expected to be served by a hydrogen pipeline in the future, as an intermediary or alternate solution, e.g. for greater control or faster implementation of their

[19] Hydrogen Blending: Government Response to Consultation, December 2023, Link

decarbonisation plans. This has not been considered in the model, which assumes a pipeline connection is used if available.

Whilst these mini clusters could fill gaps in hydrogen supply, there are some considerations for deployment:

- Where hydrogen will be used for process heat, electrification (if feasible) will be more efficient and, therefore, will likely be lower cost than using locally produced hydrogen, particularly for lower temperatures where heat pumps can be utilised. This could reduce the proportion of demand for which hydrogen is required at some sites.
- Practical factors such as a sufficient grid connection, water supply and space to site the electrolysis equipment and hydrogen storage will need to be considered.
- A single production facility is unlikely to be as reliable as a pipeline supply from a network of production sites, which may be an important factor for some applications and require mitigation.
- The economics of green hydrogen production will be location-specific; electricity is one of the largest factors in the unit cost[20] and will need to be matched with renewable sources to meet the LCHS. It is therefore most economical where these renewables are nearby so that private wire connections can be obtained, as opposed to a Power Purchase Agreement (PPA) via a grid connection which will attract transmission & distribution charges. HAR funding acknowledges that this is currently a barrier to uptake and is intended to mitigate the production cost relative to fossil fuels.

5.2.6 Hydrogen storage

The planned storage projects in the Hub region would provide approximately 4 TWh of long-term hydrogen storage by 2030, 90 % of which is from the planned Rough facility. 4 TWh represents a significant proportion of the UK hydrogen storage that is expected to be required in net zero scenarios (FES estimates approximately 20 TWh required by 2050 in Leading the Way) and if filled, could also supply the estimated Hub hydrogen demands for approximately six weeks. There is not yet a clear picture of how much hydrogen storage is required to balance a given volume of supply and demand, however, the capacity expected to be available in the Hub region indicates that it would provide a high level of resilience (UK natural gas storage is sufficient for approximately 10 days), although further analysis is required to assess the seasonal / daily flow of hydrogen.

Figure 40 shows the difference in development between peak supply/demand (in MW) and annual supply/demand (in GWh). This shows that the production volume exceeds the expected consumption (as shown in the roadmap), but that after 2030 peak demands significantly exceed the production capacity, largely due to the conversion of power stations which have a low capacity factor, but clearly require significant flows of hydrogen when running to balance the grid. This demonstrates the critical role of storage in the Hub

[20] Green hydrogen policies and technology costs, IRENA, 2021, Link

region, given the number of power stations that will potentially convert to operate as hydrogen peaking plants. A larger role of hydrogen in heating would also increase the need for inter-seasonal storage.

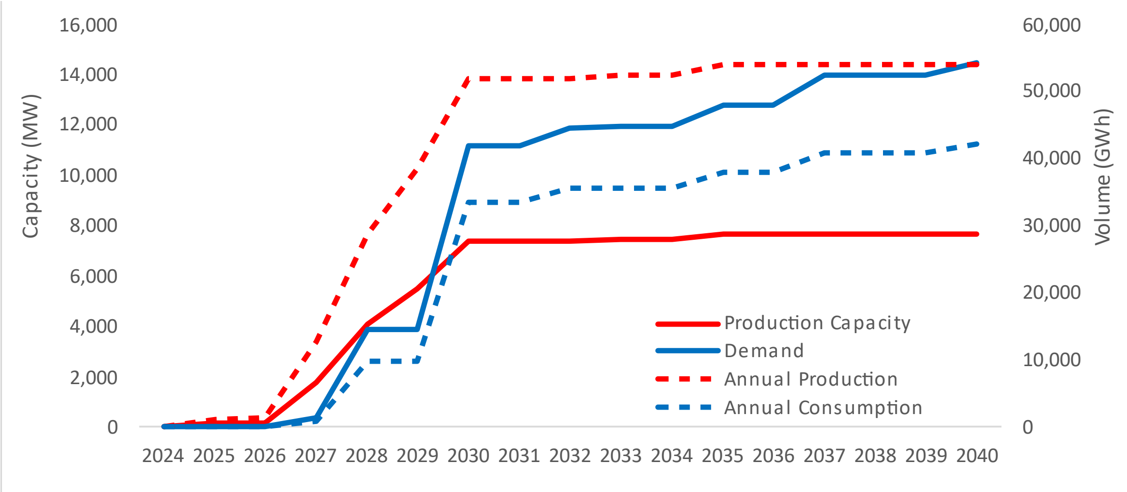


Figure 40 – Scenario 1: Hydrogen production and demand balance

The development of the Rough hydrogen storage project and the conversion from natural gas to hydrogen storage, supply, and demand (in parallel) in the Hub region is, therefore, key to both the regional and national hydrogen economy. The first phase has been included in this study, the second and third phase could increase the capacity to 10 TWh. Other identified subsurface storage opportunities that could be progressed are similar in scale to Aldborough[21] and a large number would therefore need to be identified and completed to match the Rough facility, should it be delayed or not progress.

5.2.7 Hydrogen-based fuels

The model shows that there will be significant demand (approximately 6 TWh) for hydrogen by 2050 from airports and ports, particularly Leeds-Bradford airport, Newcastle airport and Immingham port. This demand will predominantly be in the form of hydrogen-based fuels: SAF for airports, and ammonia/methanol at the ports. These will need to be produced at intermediary plants and this is where the gaseous hydrogen will be required. The finished fuels could be transported by pipeline or road/rail/sea tankers from the production plants (as is currently done for fossil fuels), and so their location is expected to be based on the availability of hydrogen, energy and other feedstocks for the fuels.

Humber and Teesside are clearly favourable locations in terms of projected hydrogen supply, and a number of production projects for hydrogen-based SAF are going ahead in Teesside as part of the government's Advanced Future Fuels program[22]. These initial projects will be self-sufficient in hydrogen supply from onsite electrolysers, and are at a small scale, but, they will take advantage of the existing chemical industry's infrastructure

[21] Storage Study Report (Appendix A12 of ECH Pre-FEED), NGN, March 2024, Link
[22] https://www.gov.uk/government/publications/advanced-fuels-fund-competition-winners/advanced-fuels-fund-aff-competition-winners

to produce SAF for local consumption or export. Significant expansion of the intermediary plants would be required to produce sufficient SAF and shipping fuels locally, although, as noted above, the model indicates that there would be sufficient low carbon hydrogen produced within the Hub region to meet this demand.

5.2.8 Regional variations

This study focusses on hydrogen development across the whole Hub region, however, there are some notable factors in the regional spread of hydrogen development, which are apparent in the maps of hydrogen assets and demand shown in Section 4:

- The vast majority of production is located within the Teesside and Humber clusters, due to their existing industrial base and access to CO_2 storage and renewable generation (necessary for large scale blue and green production respectively).
- Inland parts of the Hub region are less able to support large scale production, although a number of smaller green projects are planned, and additional potential mini clusters have been identified in this study.
- Investment is therefore driven by the construction of production plants and end-use conversion in the industrial clusters, although this could benefit the wider Hub region through workforce training and supply chain investment (see Section 6).
- Outside of the clusters, demand is largely from urban areas (with some non-domestic and industrial sites), as well as specific larger industrial sites and airports. Whilst some clusters of demand are present, in general these will not justify organic growth of a hydrogen network, therefore requiring planned development of distribution pipelines such as ECH or onsite/local production.
- Planned hydrogen pipelines are focussed on routes or areas with higher concentrations of industry. Even if these networks are constructed, not all sites (particularly those in rural areas) will have access to a pipeline supply, and this demand is generally insufficient to justify a further extension of the network. Alternative means of supply are discussed in Section 5.2.5. Further work is also required to identify sites in the non-domestic sector that are likely to require hydrogen and if/how these can be supplied.
- Where smaller production facilities are planned outside of the clusters, these can provide important investment as well as potentially stimulating further hydrogen demand.

A specific study on the West Yorkshire region was carried out, considering hydrogen supply/demand within the Combined Authority boundary and is detailed in a separate report.

5.2.9 Cohesion of projects and shared opportunities

This study collates the plans for a wide range of hydrogen assets to be developed in the Hub region. It shows when and where they will occur, as described in Section 4 for key years in the expected build out and shown interactively in the hydrogen model dashboard.

Coordination or awareness of plans for hydrogen production and consumption (which will be carried out by multiple private companies), alongside development of supporting infrastructure, has been considered in some specific areas such as the Humber and Teesside clusters (see cluster plans referenced in Appendix A).

The action plan and hydrogen working group (see Section 0) are intended to develop further evidence and facilitate collaboration between stakeholders across the Hub region. It is key that development in the Hub region is coordinated where possible and that intra-region competition is minimised. Table 8 indicates some areas of shared opportunity highlighted by this study that could be further developed.

Table 8 – Shared opportunities in the Hub region.

Information Available	Shared Opportunity
Awareness of site locations that may require hydrogen to decarbonise, in similar areas or sectors	Opportunity for knowledge and information sharing by organisations across the region where similar challenges and considerations to decarbonise are present.
Planned phases of ECH and the route/regions that this will serve	Sites to be served by each phase can collaborate with ECH and each other to better inform the business case and potentially identify other (local) offtakers
Planned locations, dates and capacities of smaller scale production plants (outside Humber and Teesside)	Potential local offtakers can understand timescales and plan for hydrogen usage that does not require a wider distribution network. Offtakers or developers can identify gaps and provide support for funding/planning applications.
Location, timing and scale of potential hydrogen demands outside of the industrial clusters	Opportunity for coordination with nearby users (particularly if local production is required or beneficial) and understanding of key 'anchor' demands in each location that can underpin the business case. Sites in similar locations that can work together for funding (to aid in conversion, local production, pipeline connection, etc.) to enable fuel switching.
Summary of production projects planned for the region and evolution of supply	Plan for timing of hydrogen availability (at scale) and support specific, key, projects. Develop a coordinated approach to relieving infrastructure constraints that may affect multiple projects.

Range of potential outcomes for hydrogen in the Hub region (indicated by scenario results)	Improve evidence base for hydrogen uptake in specific areas or sectors.

5.2.10 Investment & funding

Results presented in Section 4 show that there is an estimated investment in the region of at least £10 billion required in each scenario. This is a similar figure to that found by the ECH analysis and hydrogen development is clearly a potentially significant opportunity for the Hub region. Tens of thousands of jobs are estimated to be supported over the construction period of the planned projects, with further jobs required for ongoing operation and maintenance of the hydrogen assets thereafter. Secondary benefits of hydrogen deployment in the Hub region were not considered in this study, but might include additional investment in the region from new industry (that would not occur without a resilient hydrogen supply and distribution network), and retention of jobs & skills in the gas distribution sector. Further detailed study into the economic impact (such as carried out for the Humber Cluster[23]) could be considered.

The investment in construction and conversion is largely expected to come from the private sector, with government funding and revenue support mechanisms playing an important role in underpinning the business case for individual projects (see Section 2.2.1). This support will predominantly be via the Hydrogen Production Business Model for blue and green production projects. HAR funding, for example, reduces the initial cost premium of green hydrogen relative to fossil fuels and therefore reduces the barrier to uptake (in any sector), making it easier for a producer to secure offtakers. HAR funding would be particularly relevant for the identified smaller green hydrogen production sites.

Support is also expected from the Hydrogen Transport and Storage Business Model for the large-scale distribution and storage projects planned in the Hub region. The CCUS cluster programme is also a key mechanism to support infrastructure required for blue hydrogen production.

On the demand side, government funding is currently available to support some sectors in switching to using hydrogen, which may be crucial in unlocking demand in specific areas, particularly for early adopters (see Section 2.2.1). Funding may also be available from local/regional authorities to support specific projects or smaller sites in switching to hydrogen, as part of the net zero transition.

5.2.11 Implications for net zero

The results show that hydrogen is expected to provide a significant contribution to future energy demands in the Hub region, accounting for between 19 and 41 TWh in 2040 and displacing up to 7.5 million tonnes of CO_2 emissions at the point of use. Given the concentration of large industrial sites in sectors which likely require hydrogen to

[23] https://www.humberindustrialclusterplan.org/output-reports.html

decarbonise (see Scenario 3), it is expected to play a greater role in the Hub region than the national average. The modelling shows that most of these sites can be supplied with hydrogen either via pipeline or local production, if planned projects go ahead. There is nevertheless a risk of delays or systematic issues with scaling up hydrogen production and distribution in the Hub region, which would result in sites potentially not meeting their net zero targets.

Although not considered in this study, public awareness and acceptance of hydrogen in communities that are likely to be affected by planned developments is key. Concerns should be addressed and the case should be clearly made for the role that hydrogen can play in the net zero transition alongside other decarbonisation pathways.

Whilst some sites may require hydrogen to decarbonise, others have multiple pathways, and the timing, availability, and cost of hydrogen locally will be key factors in determining the extent to which it is utilised. Alternative pathways may face local constraints in the future, such as grid capacity for electrification, which have not been considered in this study, but may then favour the use of hydrogen if sufficient supply is available. The 'optimal' pathway for different sites or sectors in the Hub region will therefore evolve through time and should be monitored.

Whilst hydrogen produces no CO_2 emissions at the point of use, fugitive CO_2e emissions from its production and distribution should be considered as part of any assessment to understand the holistic climate impact. In the case of blue hydrogen, additional emissions from the upstream natural gas extraction and carbon capture process should also be included.

Finally, whilst some assumptions around future improvements in efficiency have been made in the modelling, a priority for all users of energy across the Hub region, should be identifying all practical opportunities for energy and resource conservation (within their sites and supply chains).

5.3 NEY Hydrogen Roadmap

Figure 41 shows a high-level roadmap for the future of hydrogen development in the Hub region. This highlights the range of outcomes based on the assessed scenarios, the key upcoming government decisions and funding models, as well as indicating the expected dates of hydrogen uptake across the different sectors.

The interdependence of supply and demand will determine the speed (and level) of hydrogen uptake across different sectors, with technological development and equipment cost also determining when this becomes a feasible option. The scope and planned operation dates for hydrogen production, distribution and storage projects are likely to change as they progress through detailed design (and construction, if a FID is obtained). This will clearly have an impact on the timelines shown on the roadmap and should be monitored for significant changes.

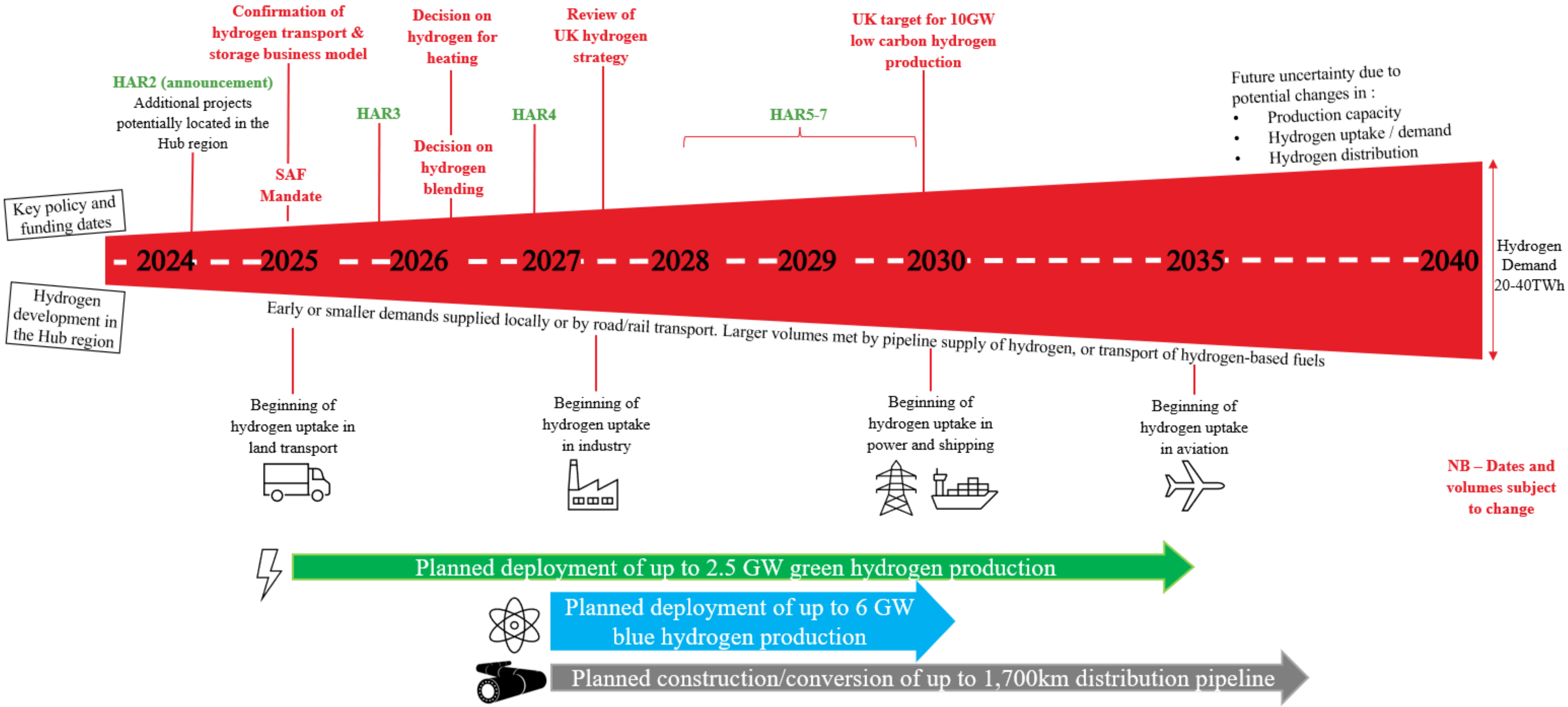


Figure 41 – Indicative roadmap of hydrogen development in the Hub region

6 SKILLS & INNOVATION

In each modelled scenario, multi-billion-pound investment in the Hub region is required to deliver the expected extent of hydrogen production, distribution and end-user conversion. The current expected timing of the deployment indicates a focused effort in the late 2020s and early 2030s. The volume of infrastructure to be delivered will require a significant scale-up of the work force, with ongoing operation and maintenance of new assets and facilities supporting a smaller number of jobs thereafter.

This section considers the high level implications for skills and innovation resulting from hydrogen development in the Hub region. The supply chain to deliver the expected new major infrastructure and change must also be considered as part of a holistic scheme's overall viability. Elements of the supply chain will be within the Hub region, predominantly including the construction and installation workforce, plus some local manufacturing, academic research, and R&D. The Hub region has a high GVA output from manufacturing, comprising a significant proportion of the UK's economy (ONS statistics and analysis carried out as part of ECH[24]). Opportunities in which the region can capitalise on the skills and assets already present locally should be explored. Other elements of the supply chain will be based outside of the region, in other parts of the UK or abroad. This is likely to include much of the manufacturing of standard parts and materials needed for infrastructure, as well as manufacture of hydrogen fuelled vehicles, vessels and aircraft. For the UK supply chain to remain competitive, continued innovation in manufacturing and a supportive policy and investment environment will be required.

6.1 Skills

A range of skills and job roles are required to design, build and operate the hydrogen assets that are planned in the Hub region. The greatest number of jobs will be associated with the construction phase (which has the largest investment requirements) and the balance of roles required though time is therefore most influenced by the construction phasing and which projects, particular larger ones, progress past the design stage (e.g. blue and green production plants will have different requirements).

Analysis for the Humber industrial cluster (see Humber section below) noted that ten key roles accounted for around 40% of engineering construction related jobs in the region currently, with these roles and their proportion expected to remain similar (albeit at a larger scale) for the development of hydrogen assets:

- Directors/managers
- Project managers
- Mechanical supervisors
- Mechanical & electrical engineers

[24] ECH Delivery Plan, November 2023, Link

- Fitters – electrical, pipe and mechanical
- Platers
- Welders
- Process operators

Whilst the roles listed above will be required across almost all projects, work carried out by ClimateXChange[25] conducted stakeholder interviews and other research to identify the skills required for specific elements of hydrogen infrastructure and where these currently reside (if available), see Figure 42. Given the existing experience in the oil and gas sector, grey hydrogen production and design engineers or operators for industrial processes, the NEY Hub region is well placed to draw on existing skills in the workforce for the majority of required hydrogen development although with some upskilling/development required as noted in Figure 42.

Supply Chain Segment	Existing Source(s) of Relevant Skills	Key Development Areas
Development of Hydrogen Infrastructure	Engineering Consultancy Sector	Specific hydrogen issues, especially safety
Installation and Commissioning of Hydrogen Infrastructure	Oil&Gas and Process Plant Sectors	Specific hydrogen issues, especially safety
Operation and Maintenance of Hydrogen Infrastructure	Oil&Gas and Process Plant Sectors	Specific hydrogen issues, especially safety
Green Hydrogen Production	Water Electrolysis at Scale is a New Process	Understanding the electrolysis process
Blue Hydrogen Production	Existing Hydrogen Production	Linking with carbon capture
CO_2 Capture	Early Examples of Post Combustion CO_2 Capture	Understanding the carbon capture process
Compressors and Liquifiers	Process Industry Sectors	Specific hydrogen issues, especially safety
Monitoring and Control	Process Industry Sectors	Specific hydrogen issues, especially safety
Pipeline Transport	Gas Transmission Sector	Materials and processes that ensure integrity of systems
Bulk Storage	Small Scale Examples / Gas Sector	Materials and processes that ensure integrity of systems
H_2 Carriers	Chemical Sector	Use of innovative carriers
Fuelling Facilities	Small Scale Examples in Transport Sector	Materials and processes that ensure integrity of systems

Key:
Strong
Moderate
Weak

Figure 42 - Extract from ClimateXChange report – hydrogen skills matrix

Work investigating skills and supply chain requirements for hydrogen deployment within the Hub region has been undertaken previously for specific areas; key findings and actions being taken are summarised below.

[25] Mapping current and forecasted hydrogen skills landscape, ClimateXChange, June 2023, Link

Humber

The HEY Business Growth and Skills Hub commissioned research[26] in 2023 which analysed green jobs and skills requirements in the region, which considered skills needed in hydrogen and alternative fuels and how these could be satisfied within the Humber region.

HEY has an active Careers Hub to support net zero jobs and a large net zero training centre is planned in the Humber area[27]. Further opportunities for coordination and resourcing in skills are expected when the Hull and East Yorkshire Combined Authority is established. The Humber Energy Board is a collaboration of private sector businesses and public sector organisations, that was setup in 2022 to act as a single voice for the Humber region. The board is committed to delivery of the Humber 2030 Vision[28], which also includes an assessment of the skills and job creation opportunities relating to decarbonisation of the cluster.

Skills analysis was also undertaken as part of the Humber Industrial Cluster Plan[29], considering the demand for specific skills and existing capacity. Stakeholder engagement showed that existing workforce pressures will be exacerbated in the delivery of net zero objectives and a critical skills shortage could occur without intervention. Market issues were identified that represent an opportunity for intervention although this analysis was not endorsed by the HEY Business Growth and Skills Hub.

Teesside

The Tees Valley Employment and Skills Strategy (2022-2029)[30] recognises that *"Tees Valley is an area of significant economic opportunity, increasingly recognised as an exemplar region in clean energy and the hydrogen economy"*. It sets out a vision where every business has access to available skilled workforce and skills development, residents have access to good jobs, progression, training and career support, and communication and awareness is clear on training routes in priority growth sectors.

Interventions being made include adult skills programmes, apprenticeships, a regional Careers Hub, Teesworks Academy (linking jobseekers with employers), and Skills Bootcamps (offering free/flexible courses including in clean energy).

Analysis of skills and jobs was also carried out as part of the Tees Valley Net Zero Cluster Plan[31] which laid out a strategic approach of "Retention, Preparation, and Intervention" to deliver the required skills.

West Yorkshire

[26] Green Jobs and Skills Analysis, Humber HEY Skills Partnership, August 2023, Link
[27] https://www.nelincs.gov.uk/catch-announces-its-vision-for-a-new-60m-national-net-zero-training-centre-expansion-at-stallingborough-headquarters/
[28] Humber 2030 Vision, May 2023, Link
[29] Lot 8 HICP Skills Analysis, April 2023, Link
[30] Tees Valley Employment and Skills Strategy, April 2023, Link
[31] Tees Valley Net Zero – Cluster Plan, July 2023, Link

The West Yorkshire Employment and Skills Framework[32] and Innovation Framework[33] explored local needs and actions. The Employment and Skills Framework agrees that a concentrated effort will be needed in ahead of 2030 and suggests that a large proportion of it will be in alternative fuels.

It recognises the importance for businesses and individuals and has convened a forum for employers and skill providers to share intelligence and review actions. It recommends further actions ranging from establishing a green skills plan and strengthening collaborations and networks, to supporting green skills in construction and engineering courses to internships, bursaries, and career programme coordination.

The Innovation Framework commits to driving forward innovation and supporting businesses to develop innovative consumer offerings, as well as providing technological and financial solutions towards meeting net zero with a just transition.

6.1.1 Challenges & Opportunities

A general increase in demand for skilled labour to deliver the roll out of net zero technologies is expected, and a workforce shortfall that threatens to throttle the intensity of delivery for hydrogen in the Hub region will need to be mitigated. The amount of economic activity is often presented as a regional or national opportunity, although the challenge must also be recognised in terms of readiness for practical deployment.

Whilst there is some crossover with existing workforce skills and knowledge, the challenge of upskilling and deploying hydrogen infrastructure (at scale) should also be recognised, with early developments in the Hub region potentially being the first of their kind in the UK hydrogen economy. Whilst training providers can develop programmes to support this buildout of infrastructure in response to demand, proactive input from employers and support for training should ideally be in place to prepare the region.

A large proportion of the activity and investment will occur within the Teesside and Humber industrial clusters, where much of the hydrogen demand and production will be located. Economic analysis for the scenarios in Section 4 shows that the installation of pipelines and conversion of smaller industrial sites in the wider Hub region is a relatively small proportion of the overall investment (increasing if more localised production is deployed). With coordination, there is an opportunity for this investment to benefit areas outside the industrial clusters by supplying skilled workers and developing the supply chain within the region.

The predicted short-term influx of skills in the region could nonetheless lead to challenges. Local small businesses, or young people without required qualifications, may be unable to contribute due to procurement or recruitment hurdles. Equally, there could be such high demand from large, concurrent projects in the industrial clusters, that workers are brought in largely from outside of the region, reducing skills development that can be retained in the Hub region and potentially causing local tensions. As well as the

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[32] West Yorkshire Employment and Skills Framework, 2021, Link
[33] West Yorkshire Innovation Framework, 2021, Link

buildout of hydrogen assets, other low carbon technologies will need to be deployed (at scale) across similar timeframes in the Hub region, with their own workforce and skillset requirements. These skills and supply chain challenges can, and must, be addressed through coordinated policy and initiatives across the private and public sectors. In addition to the direct and indirect jobs supported, there is a significant opportunity for social value outputs, supported by local careers hubs and voluntary organisations.

6.2 Research and innovation

The skills of the future will be driven by the research and innovation of today. The nature of the nascent hydrogen economy requires infrastructure and end-use technology needing innovation across the supply chain. This is a narrative that holds true across the UK and will be particularly relevant in the Hub region.

It will be important for entities in the Hub region to collaborate nationally and internationally on research and innovation. There are 15 universities in the Hub region which can help to drive forward this agenda, particularly when linked with industry, such as the Aura Innovation Centre in Hull[34]. There are also several industry bodies that can collaborate to help address key challenges, such as CATCH, NOF and the Hydrogen Innovation Initiative.

The maturity of technologies and innovations needs to progress along the nine Technology Readiness Levels (TRL). This is where there is a role for small and medium enterprises, to rapidly test and develop concepts to bring them closer to market readiness. Research funding from agencies such as UKRI is also critical to make this happen and to provide focussed effort on key challenges, such as bringing down the cost of, and ensuring the safety of, hydrogen development.

The Humber and South Yorkshire freeports, as well as four investment zones[35] (North East, Tees Valley, South Yorkshire and West Yorkshire), will also potentially provide attractive locations for new manufacturing and research facilities, with funding allocated specifically to boost innovation and create jobs.

Finally, for deployment at scale, it is often larger companies with the support of trusted consultants, who have the resources to take the risk and drive forwards large scale projects. The Hub region has all these entities in abundance and can play an active role in stimulating and coordinating this drive.

[34] https://aura-innovation.co.uk/
[35] https://www.gov.uk/guidance/investment-zones-in-england

6.3 Summary

Table 9 shows a summary of the high-level strengths, weaknesses, opportunities and threats (SWOT) relating to skills and innovation in the Hub region.

Table 9 – SWOT relating to skills and innovation

Strengths (internal)	**Weakness (internal)**
• UK-leading planned deployment of hydrogen production and connecting the country's two largest industrial clusters, means a strong growth predicted to 2030 and beyond • Large base of existing industrial expertise including in hydrogen demand • Broad base of demand sectors that could convert – expertise across whole hydrogen economy	• Extent of deployment is dependent on deployment of large, single projects such as blue hydrogen production (including CCUS) and ECH distribution pipelines • Post-industrial decline in the last century has led to deprivation and associated skills challenges in some areas. Those without qualifications can find it hard to participate despite experience.
Opportunities (external)	**Threats (external)**
• Opportunity to be a first mover, to train, attract, and retain skilled people in the Hub region ahead of the other industrial clusters. Then, later, skills and the supply chain can be exported outside the region, once developed on existing projects • Develop and patent innovations to enable development within the Hub region and export nationally/globally • Collaboration with other regions and projects • Opportunity to think ahead to upskill workers in the region who could otherwise be left behind	• Changes in plans and lack of coordination could lead to peaks & troughs in employment and pressure on supply chain • Change in government funding or policy could significantly affect development of wider hydrogen network/ecosystem • An influx of workers from outside the region could lead to local tensions if not properly addressed. • Competition for skills with other clusters or other parts of the UK could make it hard to attract resource • Risk that UK supply chain is not competitive or sufficiently developed to capitalise

7 NEY HUB ACTION PLAN

As noted in Section 1, the Hub's aim is to help accelerate the Hub region's ambitious efforts to drive a low carbon, clean growth future. This study provides some insights into the role that hydrogen can play in a decarbonised future and highlights how hydrogen development may be spread across the region. This section details a hydrogen action plan for the Hub region based on findings from this study and details of a hydrogen working group for the region. As noted previously, the hydrogen industry in the UK is still nascent, so subject to high levels of uncertainty across the supply chain in terms of production, offtake and final use applications. Eliminating these uncertainties is key to success. This is dependent on a mixture of secure, long lasting policy at a regional and national level, de-risking both public and private investment, and long lasting collaboration crossing politics and industries to a common goal of hydrogen use as an essential part of Net Zero.

7.1 Action Plan

During the course of the study, and based on its findings, a number of actions were identified that could be undertaken by the Hub and the hydrogen working group to support hydrogen development in the region. The actions identified at the Hub-level focus on the Hub's role as a coordinating organisation. The WYCA deep dive study (reported separately) is an example of how more specific actions or policy recommendations for individual CAs/LAs can be defined.

The Hub action plan is included in Appendix D and actions are organised into three broad categories:

- Leadership & coordination
- Develop evidence
- Enable/support deployment

It is expected that one of the first tasks for the hydrogen working group is to review and formalise the action plan, identifying initial tasks and appropriate owners for each item (from LAs, CAs, private sector organisations etc.), and when progress against each should be reviewed. The group should also discuss how sustained engagement and buy in from all members, alongside the Hub and partners, can be ensured. As noted previously, the hydrogen sector is evolving rapidly and the action plan will need to be maintained as a live document to reflect changes in, for example, technology, policy, and costs, that occur and to ensure that effort is prioritised appropriately.

This study covers a wide range of aspects relating to hydrogen development but is not exhaustive, and other supporting actions should also be identified and considered where appropriate.

7.2 Hydrogen Working Group

The hydrogen working group is primarily intended to own and progress the implementation of the action plan, supporting hydrogen development in the Hub region. Initial action plan items are put forward in this report, and it should be maintained as a live document, which will need to be adopted and owned by each of the Hub region's six constituent regions (taking into account recent changes in political structure relating to devolution).

The working group is also intended to function as a discussion forum for developments in the region, and to provide a degree of coordination on hydrogen-related activities and engagement, alongside other national/regional bodies.

The structure and constitution of the group are to be determined and should provide appropriate alignment between the group and regional ownership. Proposed members are listed in Table 10, these organisations were selected in order to achieve a representation from across the demand sectors present in the Hub region, as well as the hydrogen supply chain and other key stakeholders. Ongoing leadership or chairing of meetings is suggested to be by the NEY Hub, but this would be subject to board approval.

Table 10 - Proposed hydrogen working group membership

Organisation	Sector	Rationale
NEY Hub (and constituents)	Public Sector	Convener
Arup	Consultants	Organise initial meeting
East Coast Hydrogen (includes NGN and Cadent)	Hydrogen Distribution	Significant project in the region
Equinor	Hydrogen Production	Involved in significant projects in the region
SSE		
BP		
EDF		
HyGen		
Enfinium		
Universities (number TBC)	Academia	Provide third party research input
Net Zero North East England	Third party organisations	Represent a wide range of public/private interests
Leeds and/or Yorkshire & Humber Climate Commission		
North East England Chamber of Commerce		
CATCH	Industry	Represent a wide range of industries with involvement in hydrogen
NEPIC		
NOF Energy		
CPH2		
Transport for the North	Transport	Represent key sites and industries in the region
British Ports Association		
Leeds Bradford Airport		
Newcastle Airport		

APPENDIX A - INFORMATION GATHERING

A.1.1 Stakeholder Engagement

Table 11 lists the organisations that attended the online workshop.

Table 11 - Workshop attendees

Organisation	Category	Organisation	Category
Arup	Project Team	Arriva	Private Sector
NEY Net Zero Hub		CPH2	
Local Authorities (x11)	Public Sector	Energy Oasis	
Durham University	Academia	Exolum	
Hull University		Geopura	
Leeds University		Glentrool Asset Management	
Newcastle University		Johnson Matthey	
Teesside University		NOF	
Confederation of British Industry (CBI)	Third Party	Northern Gas Networks	
Leeds Climate Commission		Protium	
Offshore Renewable Energy (ORE) Catapult		Tata Steel	
Trades Union Congress (TUC)		Ulemco	

A.1.2 Literature Review

Key studies (national and region-specific) that were used to inform the roadmap study are listed in Table 12.

A Local Area Energy Plan (LAEP) is currently being produced for WYCA and other parts of the Hub region are expected to commission LAEPs in the near future. In general, LAEPs consider the full range of future energy vectors and demands, including hydrogen, as part of a holistic assessment. This study provides a more granular sectoral breakdown of hydrogen demand and considers the location of each asset in greater detail than LAEPs but the two approaches can be used to provide a degree of verification on assumptions made and test findings.

Table 12 – Relevant studies informing the hydrogen roadmap and assumptions

Study/Report	Date	Relevance
CCC - 6th Climate Budget	Dec 2020	Independent assessment of UK net zero trajectories
National Grid - Future Energy Scenarios	Jul 2023	Independent assessment of UK net zero trajectories
National Infrastructure Commission – Second National Infrastructure Assessment	Oct 2023	Policy and technology assessments of different sectors
Energy Systems Catapult - Innovating to Net Zero	Apr 2024	Assessment of low carbon energy and technology uptake in different scenarios
Northern Powergrid – Distributed Future Energy Scenario	Feb 2024	Regional assessment of net zero trajectories
York and North Yorkshire - Local Area Energy Plans	Nov 2023	Regional assessment of future energy supply and demand
WYCA - Carbon Emissions Reduction Pathways (CERP)	July 2020	Identify how WYCA's 2038 target could be met in different scenarios
East Coast Hydrogen - Delivery Plan	Nov 2023	Considers regional hydrogen demands and routing of distribution pipelines
Humber Industrial Cluster Plan	Mar 2023	Outline plans for decarbonising two of the UK's largest industrial clusters by 2040
Tees Valley Net Zero Cluster Plan	Jul 2023	
A vision for hydrogen in the Tees Valley	Nov 2022	Brings together public and private players to create a Tees Valley narrative on hydrogen
Transport for the North (TfN) - Hydrogen Mobility Visualiser	Mar 2024	Models potential hydrogen demand for road & rail transport across the north of England

A.1.3 Energy demand data

The hydrogen model requires a baseline of energy consumption for each of the in-scope sectors (see Section 1.3.2) where hydrogen could play a future role. To provide greater fidelity in the modelling it is desirable to subdivide some of these sectors as well as obtaining location-specific demands, although the ability to do this is largely determined by the datasets available. Following a review of available data, a mix of public and proprietary datasets were used to estimate the current energy demand for each category and are shown in Table 13. A hierarchy of data sources was established which provided greater confidence in estimates, particularly for the highest consumption sectors where individual sites can be responsible for a large proportion of demand in a given sector/area.

This process resulted in energy demand within the Hub region being divided into 35 categories (23 of which are industrial sectors from the NAEI dataset) which is judged to provide a sufficient level of detail for the hydrogen model and captures the key relevant sub-sectors in the Hub region. It should be noted that the calculated baseline energy demands contain some uncertainties and assumptions and so are not expected to be fully accurate, however they are judged to be sufficient for this roadmap study and capture the key magnitudes and locations of the demand across the Hub region.

Some datasets provide information on the specific location of energy demands (e.g. for large industry), in other cases the demand data is aggregated over an area (such as MSOA-level data for domestic & non-domestic gas consumption).

Further information on how the baseline energy demands are used within the model is given in Section B.1.4.2.

New sites with known plans for significant hydrogen demands (that would not be satisfied by on-site production) were also included. Only the Keadby 3 hydrogen peaking power plant[36] has been considered as a significant consumer at this stage.

[36] https://www.keadbyhydrogen.com/

Table 13 - Energy demand categories considered in the study

Group	Sector	Current Fuel	Public Dataset	Supplementary Dataset	Assumptions
Space Heating & DHW	Domestic	Natural gas	UK residential MSOA gas consumption data	N/A	Non-gas consumption data not collected – assumed that off-gas grid homes are unlikely to switch to hydrogen
	Commercial		UK non-domestic MSOA-level gas consumption data	N/A	Assume split between commercial and small industry in line with DUKES[37] data
	Small Industry (inc. process heat)				
Power Generation	Large Power Stations	Natural gas	NTS Offtakers	NGN & Cadent demand data	Saltend and Immingham CHP plants are counted as power stations in this study
	Major & Minor Power Producers*		NAEI Large Site Emissions		Assume that emissions from NAEI data are from natural gas combustion
Transport	Buses	Diesel	Total number of buses Bus depots		Assume a typical efficiency & distance travelled to estimate overall fleet demand
	HGVs	Diesel	DfT energy and environment data		
	Rail	Red Diesel			Assume that only non-electrified lines might convert to hydrogen
	Aviation	Aviation fuel (Jet A1)			
	Shipping	Marine fuel oil	DUKES and NAEI		
Industry	x23 as per NAEI dataset[38].	Natural gas	1) NTS Offtakes 2) NAEI Large Site Emissions	NGN & Cadent demand data	Discount proportion of emissions that could not be removed via hydrogen (e.g. process emissions). Assume that remainder are from natural gas combustion or production of grey hydrogen

* as per NAEI definition
[37] https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes
[38] https://naei.beis.gov.uk/data/map-large-source

A.1.4 Hydrogen asset data

A.1.4.1 Hydrogen Production

Production assets refer to planned production projects, of which there are more than 20 in the Hub region (see Table 14). These total approximately 50GW of production capacity between blue and green hydrogen and Figure 43 shows that these are largely concentrated within the two industrial clusters. An additional 300MW capacity is classified separately as it is from a planned facility that would import and crack green ammonia to produce green hydrogen.

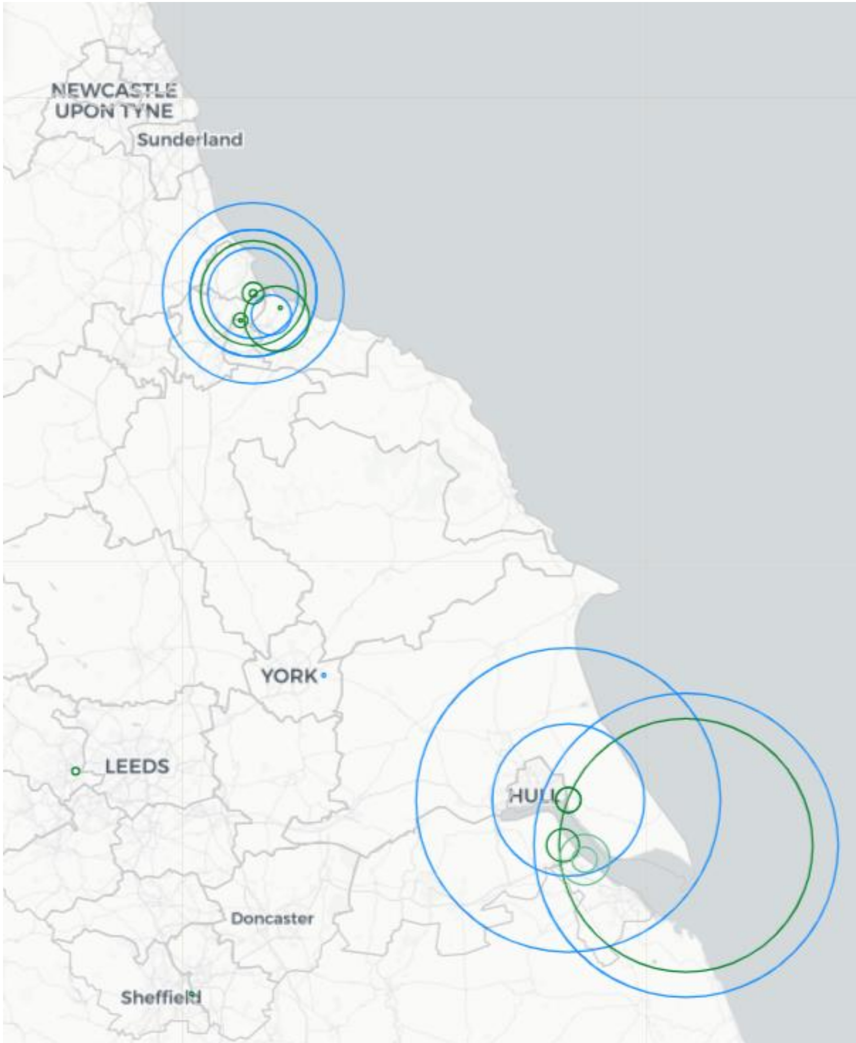

Figure 43 - Planned hydrogen production projects in the Hub region

Of most interest for the model is the location, startup date, capacity (including any future phased expansion) and technology for each production plant. Further assumptions relating to production plants are then made within the model, these are discussed further in Appendix B.

The data collated shows that the majority of these production projects are expected to be complete by 2030. Further projects are expected to be announced as the hydrogen economy develops (particularly if supporting infrastructure is available within the region), this is discussed further in Section 5.2.3. The model also includes the functionality for new, demand-led production to be created – see Appendix B.

A.1.4.2 Hydrogen Distribution

In this study distribution assets refer to planned hydrogen pipelines (either newbuild or repurposed natural gas pipelines) that would operate as part of the following systems:

- National Transmission System (NTS) – very high pressure (>40bar)
- Local Transmission System (LTS) – high pressure (>7bar)
- Local distribution – intermediate & medium pressure (>2bar)

The model used in this study considers further connections off the planned hydrogen pipelines (see Appendix B), these are generally to specific large sites or an aggregated area which are therefore assumed to be at medium pressure or greater. The low pressure hydrogen distribution network (e.g. to individual homes or businesses) is not considered in this study.

Within the Hub region, there are two planned projects for the deployment of hydrogen pipelines:

1) Project Union is a National Gas project to provide a hydrogen 'backbone' for the UK (see Figure 44) and is intended to link the Teesside and Humber clusters, largely by repurposing existing NTS pipelines, by 2030[39].

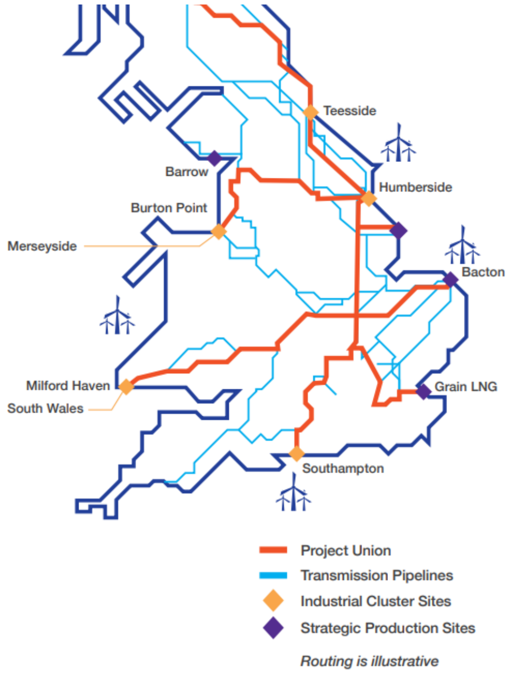

Figure 44 - Project Union indicative routing

2) East Coast Hydrogen (ECH) is a collaboration between National Gas, NGN and Cadent, with the intention to create a LTS for hydrogen to serve consumers the east coast region[40]. The Project Union link between Teesside and Humber serves as the core of the ECH network, with a range of spurs and branches (using newbuild or repurposed pipeline) built off this in phases that will be completed between 2028 and 2037, see Figure 45.

For this study, the following data was used in the model:

[39] Project Union Launch Report, May 2022, National Gas, Link
[40] East Coast Hydrogen Delivery Plan, November 2023, ECH, Link

- GIS data on the planned hydrogen pipeline routing, for Project Union (within the Hub region) and ECH (within the NGN area). In the Cadent area GIS data was not available, and the approximate pipeline routing was manually entered.
- Planned timescales from the delivery plans of both projects

Based on current plans for hydrogen production and distribution projects there is a particular dependency for the Hub region on ECH to supply hydrogen to demands located further away from the Humber and Teesside clusters. Variations in ECH (such as pipeline routing, timescales etc.) will therefore have the largest impact on hydrogen development in the Hub region of any of the considered hydrogen asset projects.

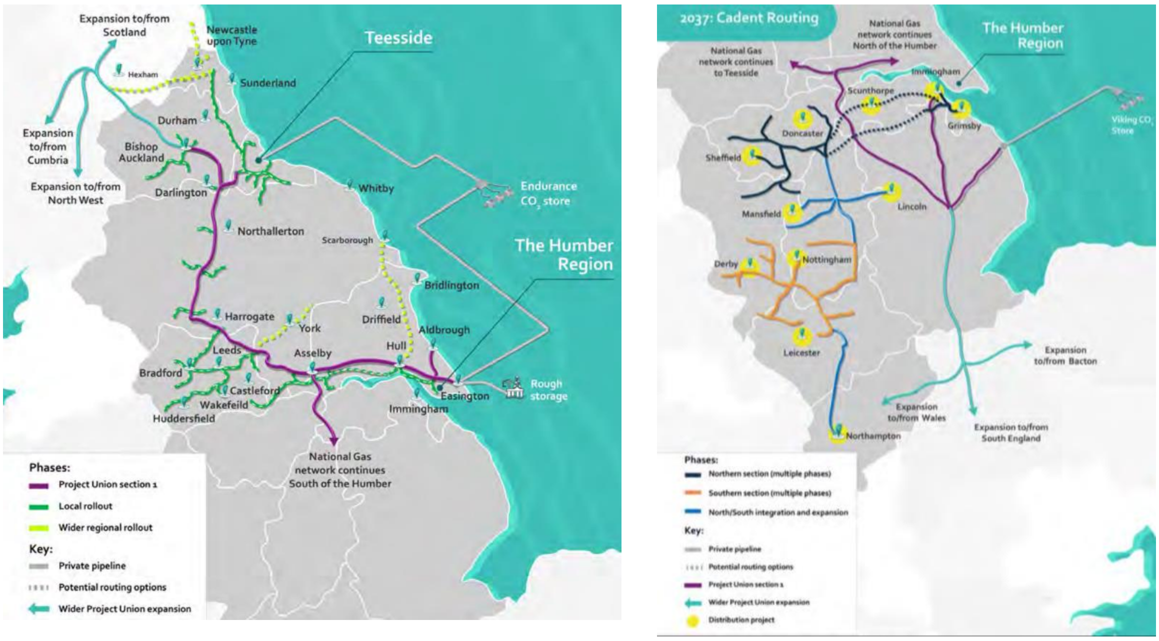

Figure 45 - East Coast Hydrogen planned pipelines (final planned layout in 2037)

A.1.4.3 Hydrogen Storage

As the model operates on an annual basis, the charge/discharge of storage is not considered explicitly. The location of planned projects (and any pipeline connections) are therefore included in the model to act as additional supply points on the hydrogen network.

Two subsurface storage projects are currently planned in the Hub region; Aldborough[41] (0.3TWh in salt caverns) and the Rough[42] (3.3TWh in the depleted natural gas field, for the first phase). Linepack storage within distribution pipelines was not considered.

A.1.4.4 Hydrogen Project Summary

Table 14 shows the list of projects included in this study and also indicates those which have been successful in applying for funding or support through some of the available schemes, although in some cases negotiations are ongoing. Other sources of hydrogen

[41] Aldborough Hydrogen Storage, Accessed April 2024, SSE Thermal & Equinor, Link
[42] The reopening of Rough gas storage, October 2022, Centrica, Link

production that do not currently meet the LCHS (e.g. at EfW sites such as Ferrybridge[43]) are not currently considered.

The list is based on information available from the HydrogenUK database at the time of writing. There are additional projects planned in the Hub region which are currently at concept stage or are confidential, these are not included in the study but should be considered if/when further details are announced. New projects in the Hub region may also be announced following the results of HAR2 or future funding rounds.

43 https://enfinium.co.uk/esg/hydrogen/

Table 14 - Hydrogen projects (existing or planned) in the Hub region that are included in the model

Project Name	**Organisation(s)**	**Type**	**New Capacity ($1^{st}/2^{nd}$ Phase)**	**Announced Funding/ Support**	**Planned Operating Date**
Hydrogen-to-Humber (H2H) Saltend	Equinor	Production (Blue)	600 / 1200 MW		2027 / 2029
Easington Hydrogen	Equinor, Centrica		1200MW		2028
Humber H2ub (Blue)	Uniper		720 MW		2027
H2NorthEast	Kellas Midstream		355 / 710 MW	NZHF	2028 / 2030
H2Teeside	BP		500 / 500 MW	Track 1 CCUS Cluster	2027 / 2030
Teesside Hydrogen CO2 Capture	BOC		150 MW		2027
Easington Hydrogen	Equinor, Centrica	Production (Green)	1000 MW		2028
HyGreen Teesside	BP		80 / 420 MW		2025 / 2030
Wilton Green Hydrogen	RWE		260 MW		2030
Humber H2ub (Green)	Uniper		120 MW		2029
ITM Humberside	ITM		100 MW		2035
Meld Energy Green Hydrogen Hub	Meld Energy		100 MW		2028
Tees Valley Net Zero Hydrogen	Protium		17 / 52 MW		2025 / 2026
Aldbrough Hydrogen Pathfinder	SSE		35 MW		2025
Tees Valley Transport Hub	Cenex, Arcola		26 MW		2025
Bradford Low Carbon Hydrogen	Hygen, N-Gen		25 MW	HAR1	2025
Project Mayflower	Uniper		20 MW		2025
Tees Green Hydrogen	EDF, Hynamics		5 / 200 MW	HAR1 / NZHF	2026 / 2030
Tees Valley Hydrogen Vehicle Ecosystem	Exolum		5 MW	NZHF	2025
Hydrogen Mini Grid - M1 Rotherham HRS	Motive Fuels		1 MW		2015
Immingham Green Energy Terminal	Air Products	Ammonia Cracking	100 / 200 MW		2029 / 2035
ECH (including Project Union)	NGN, Cadent, National Gas	Distribution	N/A		2028, 2031, 2032, 2037
Aldbrough Storage	Equinor, SSE	Storage	320 GWh		2028
Rough Storage	Centrica	Storage	3,300 GWh		2030

APPENDIX B - HYDROGEN MODEL

Figure 46 shows the key steps used in the hydrogen model – this Appendix provides additional detail on each of these steps in turn.

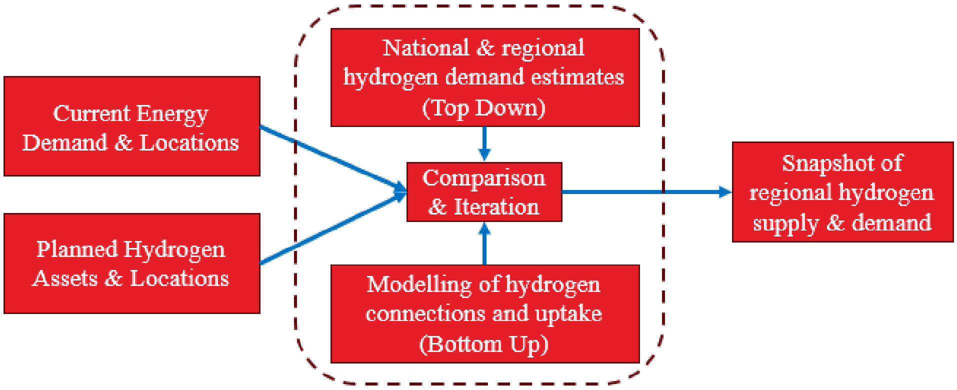

Figure 46 - Hydrogen model overview

B.1.1 Current energy demand & planned hydrogen assets

Appendix A provides detail on how the current energy consumption of sites in the Hub region is estimated. This defines the baseline energy input from fossil fuels that could be replaced by hydrogen, for each sector in the Hub region. Appendix A also shows how the information on planned hydrogen assets is obtained, these are stored in the hydrogen model with a number of fields that determine their key parameters (such as capacity, date of operation, owner etc.).

B.1.2 Hydrogen Uptake Factors

A key part of this study is determining the role (if any) of hydrogen in decarbonising a given sector in the Hub region.

B.1.2.1 Sectoral Hydrogen Uptake – National Values

At a national level there are already several independent studies which project the adoption of hydrogen and other decarbonisation options in different sectors through time, for example the National Grid Future Energy Scenarios (FES) and Climate Change Committee (CCC) 6th Carbon Budget. These studies are evidence-based, peer-reviewed and cover 4-5 different scenarios. Both studies use multiple criteria to determine the balance of technologies that will be used in each sector, taking into account the cost, supply volume, geography, technology readiness and other factors to find an optimal mix that achieves (or does not achieve) a 2050 net zero target.

A national-level scenario is used as the starting point for the roadmap study, providing an initial value for the uptake of hydrogen in each sector. The National Grid FES 'Leading the Way' scenario was chosen; this was produced more recently than the CCC study (therefore having more recent input data) and is judged to most closely resemble the expected uptake in the Hub region, where hydrogen consumption is predominantly in hard-to-decarbonise industrial sectors.

The published FES data shows the 2023 energy demand and the 2050 hydrogen demand in a range of sectors, which provides an overall 'uptake factor' to convert between current fossil fuel consumption and future hydrogen demand. This factor includes the FES assumptions around sector growth, efficiency improvements, the relative efficiency of hydrogen vs. the current fuel and the expected role of hydrogen vs. alternative decarbonisation technologies. The sectors used in this study can be directly read across from FES, except in industry where it is not broken down to the same level of granularity.

B.1.2.2 Sectoral Hydrogen Uptake – Regional Values

Uptake factors taken from the FES data are a good starting point but are derived from national-level considerations and, as mentioned, do not differentiate between industrial sectors. The Hub region is not 'typical' given the presence of the Teesside and Humber clusters, the range of industry (in the clusters and elsewhere), so hydrogen uptake is unlikely to follow the same pattern or trajectory as the UK average. It is therefore desirable to 'localise' the hydrogen uptake factors and take account of the regional characteristics to provide a more representative estimate of future hydrogen demand.

The localisation process involved adjusting the FES uptake factors, up, down (to zero if justified), or leaving as the national average if no 'better' information was available for the Hub region. This process used quantitative data and insights where available, with some qualitative engineering judgement also applied.

Several sources were considered when localising the sectoral uptake factors:

- Other studies that have already looked into the future use of hydrogen in the Hub region, for one or more sectors (see Section A.1.1)
- Developments since FES was published in late 2023, such as changes in technology, policy and funding
- Local policies or funding that may influence the proportion of demand in a given sector that switches to hydrogen, or influence the likelihood of production/distribution assets being constructed and affect the amount of hydrogen available locally
- Evidence from public announcements or stakeholder engagement that a specific site/industry in the region is more/less likely to convert
- Proximity to a hydrogen production facility or part of a wider hydrogen network may increase the likelihood of a given sector/site switching to hydrogen

Given the limited evidence for hydrogen uptake to date and uncertainties in technologies, costs, etc. this is an inherently imprecise process and it is therefore the *direction* and *scale* of adjustment from the FES national average that is the key outcome from the localisation. This indicates the approximate role that hydrogen is expected to play in each sector and the hydrogen uptake factors are listed in Table 15.

B.1.2.3 Model Uptake Factors

Table 15 – Hydrogen uptake factors

Sector Group	Sector	Top Down Uptake Factor	Rationale
	Domestic	5%	Limited evidence that supports hydrogen for heating at scale
	Non-Domestic	17%	Weighted combination of 5% uptake in commercial buildings and 50% uptake in small industry
Power	Large Power Stations	Variable	Adjusted such that each power station has a future capacity factor of approximately 15%
	Major Power Producers	0%	Relevant sites in the region are already using biomass or EfW
	Minor Power Producers	15%	Potential for some uptake in smaller scale CHP or at specific sites
Transport	Vans	0%	EVs expected to dominate
	HGVs	30%	Based on literature review, with longer range HGVs adopting
	Buses	10%	Based on literature review, with a small proportion of routes requiring hydrogen
	Rail	0%	Based on literature review, minimal uptake expected in Hub region
	Aviation	20%	Based on literature review, limited proportion of hydrogen-based SAF
	Shipping	120%	Switch to ammonia/methanol and sector growth
Large Industry (NAEI Groups)	Chemical industry	66%	Adjusted FES value
	Food, drink & tobacco	66%	Adjusted FES value
	Cement	N/A	
	Other mineral industries	70%	Adjusted FES value
	Processing & distribution of petroleum products	30%	Covers grey hydrogen proportion, several sites expect to use CCUS rather than alternate fuels
	Public administration	5%	Space heating assumed to be same uptake as domestic
	Iron & steel industries	0%	Sites in the Hub region not expected to use hydrogen based on known plans
	Waste collection, treatment & disposal	0%	
	Lime	0%	
	Vehicles (manufacture)	0%	
	Construction	47%	These sectors represent a small proportion of overall demand in the Hub region. The FES average industry uptake was therefore assumed, with individual sites able to utilise hydrogen if in range of supply in the bottom up modelling
	Textiles, clothing, leather & footwear		
	Paper, printing & publishing		
	Non-ferrous metal industries		
	Mechanical engineering		
	Electrical engineering		
	Other industries		
	Water & sewerage		
	Agriculture, forestry & fishing		
	Oil & gas exploration and production		
	Processing & distribution of natural gas		
	Other fuel production		
	Miscellaneous		

B.1.3 Top-Down – future hydrogen demand

The top-down method is used to estimate the hydrogen demand at a sector level for the Hub region through time. The hydrogen uptake values for each sector (derived in Section B.1.2) are multiplied by the baseline energy demand to calculate the future hydrogen demand. This method does not account for site-specific factors and does not provide any indication of whether the demand could be supplied (except for a simple comparison with gross production in the region). The top-down results are intended to provide an overall estimate of demand that can be linked to specific data from the literature review, in combination with some justified regional adjustments. These results also provide a comparison point for outputs from the more detailed bottom-up methodology and other previous studies.

B.1.4 Bottom-Up – future hydrogen demand and growth of hydrogen network

The bottom-up method is an independent approach used to estimate the potential hydrogen demand in the Hub region. The key difference to the top-down method is that it explicitly considers the location and layout of a future hydrogen network to determine which hydrogen demands can be supplied, and when.

The results presented in this study are predominantly from the bottom-up method as this is judged to provide the most representative view of how hydrogen supply/demand in the region will develop, with a level of verification on the overall hydrogen demand provided by the top-down method.

The bottom-up method works through year-by-year, each time following the high-level steps outlined in Table 16 to build out new assets and check whether demand sites are able to connect to the hydrogen network. Further detail is given in subsequent sections.

Table 16 – Bottom-up methodology

Bottom-Up Methodology Step	Description
1) 'Build' or extend hydrogen network	The data on hydrogen assets described in Section A.1.4 provides the underlying data for the build out of the hydrogen network, i.e. when and where new production, distribution and storage is built and at what scale.
2) Calculate new (hydrogen) demand at each site	The baseline energy demand at each site is converted into a future hydrogen demand based on a number of parameters
3) Determine whether site is viable to connect	The distance to the nearest hydrogen supply point is calculated, and the site is 'connected' if a defined threshold of demand vs. distance is exceeded.
4) Update model with new extent of the hydrogen network	The state of the hydrogen network is saved for this year, the model then moves to the next year and repeats steps 1-4

B.1.4.1 Methodology 1 – Build out of hydrogen assets

The data gathered on the hydrogen assets provides the location, capacity and operational date. These are enabled within the model at the specified operational date and then act as parts of the hydrogen network (see Section B.1.4.2 below), as single points for production plants and planned routes for hydrogen pipelines.

Some additional assumptions are applied to each of the assets to reflect their expected characteristics and ensure that the model is representative.

- It is assumed that production plants can supply at their full capacity from their announced operational dates, with any reduced supply during prior commissioning/testing not being considered.
- Production sites are assumed to operate with a capacity factor of 80%. This is typical for large industrial facilities, and can be refined as operational data from large scale blue/green hydrogen production becomes available.
- Production sites with offtakers that account for their entire production (e.g. the majority of HAR1 projects, or facilities supplying only a nearby SAF plant) are not considered part of the wider hydrogen network.
- Detail on the sub-phasing of hydrogen pipeline construction is not available and so it is assumed that all parts of each ECH phase come online at the stated operational date.

As noted in 1.3.2, supporting infrastructure for hydrogen assets is not explicitly considered and the model does not constrain the build out of hydrogen assets.

B.1.4.2 Methodology 2 – Calculating hydrogen demand at each site

In the bottom-up method, the baseline, counterfactual energy demand for each site is adjusted each year to take account of sector growth and energy efficiency. It is implicitly assumed that each site operating in 2023 continues to do so in the same manner through to 2050. Some, all or none of this baseline demand will be converted to a potential hydrogen demand in the model, as determined by a combination of the following factors:

- Whether hydrogen can be used in the given year – determined by a technology feasibility date for each sector. This prevents sites switching to hydrogen before a given date and reflects the different TRL for hydrogen technologies, noting that it is already available in 2024 for some.
- For each sector, the proportion of energy demand that is met with hydrogen in the first year that technology is commercially available, and 10 years after the introduction.
    - This models the rate of uptake within a given sector, i.e. whether it would be a gradual replacement of equipment or a rapid adoption
    - It also models the 'final' uptake of hydrogen within a given sector, i.e. the role of alternative technologies in replacing fossil fuel use. The selection of this proportion is based on similar evidence to the localisation discussed in Section B.1.2.
- Efficiency of hydrogen technology when replacing current fossil fuel demands. For example, a hydrogen fuel cell is more efficient than a combustion engine and therefore fewer kWh of hydrogen than diesel are required. Constant factors for each subsector are used in the model based on comparisons of current technologies. These are simplifications but judged sufficient to estimate the volume of hydrogen required.
    - For space heating, power generation and industry, hydrogen is assumed to be used at the same efficiency as natural gas.

- For buses, HGV and rail, hydrogen is assumed to be used in fuel cells at higher efficiency
- For shipping, ammonia is used at a similar efficiency to marine fuel oil in combustion engines but contains a higher energy content of hydrogen
- For aviation, SAF is used at a similar efficiency to conventional jet fuel and contains a lower energy content of hydrogen

The net effect of these parameters is to provide the model with an evolving picture of *potential* hydrogen demand (at specific locations) through time. The connection threshold (see Section B.1.4.3) then determines whether these demands are actually met from the available infrastructure.

B.1.4.3 Methodology 3 – Hydrogen connection threshold

A key part of the bottom-up method is determining if/when hydrogen demands can be supplied from the available hydrogen assets. As noted in Section 1.3.2, this methodology considers pipeline connections of gaseous hydrogen. Within the model, the following steps are followed each year to determine whether a site can be connected and supplied, which represents the growth of a hydrogen network through time from both the planned deployment of larger hydrogen pipelines and the 'organic' growth of additional pipelines:

1) Check the distance between any unconnected hydrogen demands and the nearest hydrogen supply point (this could be a production site, any point on a hydrogen pipeline, storage site or another hydrogen demand site that is already connected)
2) Divide the annual hydrogen consumption for each unconnected site by the distance from a hydrogen supply point to obtain the connection value (in GWh per km)
3) If the connection value is greater than a defined threshold (50GWh/km), 'build' a pipeline between the demand site and the hydrogen supply point and treat it as connected and supplied

The connection threshold is intended to place a constraint on the buildout of hydrogen pipelines (new or repurposed), representing whether the connection offers value for money for the gas network operator (e.g. construction of an extensive pipeline to supply a small consumer is unlikely to recoup the investment from standing charges etc.). The metric used for the threshold is a simplification but is considered sufficient to identify which sites would 'justify' a hydrogen connection and which are likely to be too far from the future hydrogen network to connect. The derivation of the threshold value used in the model is discussed in more detail below.

This process has the following effects for different sites:

a) Some demand sites are 'automatically' supplied by the planned deployment of hydrogen pipelines such as ECH, which is specifically routed via large consumers. After the pipelines are included in the modelled buildout of assets, these sites are at effectively zero distance and will connect.
b) Other sites may connect via new pipelines in the first year that they are assumed to have a hydrogen demand, if the combination of demand and distance to the network already exceeds the connection threshold.
c) Some sites will not initially have sufficient hydrogen demand to exceed the connection threshold, but as their demand increases through time they may exceed the threshold and connect in a later year, or when the hydrogen network effectively moves closer due to other connections
d) Some sites with potential hydrogen demands may never meet the connection threshold and will not be connected

The model tracks the quantity of installed pipeline, from both planned projects and organic growth.

Further assumptions with this method:

- The model does not constrain the quantity of new pipeline that can be added each year.
- It is assumed that once connected, a site continues to use hydrogen (and therefore acts as a supply point on the hydrogen network)
- The methodology described in this section is intended to represent the growth of lower pressure / local distribution pipelines, rather than larger scale transmission pipelines. The existing work on ECH provides an assumed buildout for this and given the complexities and factors (such as gas flows and routing) an independent methodology has not been included in the model.
- A single threshold value is used for all sectors and all locations – in reality the cost of installing new pipeline will vary depending on whether it is in a rural or urban location and also considering natural features. Some sites or sectors may be willing to pay a premium for a hydrogen connection, if they do not have viable alternative decarbonisation plans.

Determining connection threshold value

Analysis of heat networks considers the linear heat density (LHD), i.e. an overall measure of the 'efficiency' of the network. This is an approximation of how much revenue the overall network (or a specific branch) can generate for a given capital cost. The same principle is applied to the future hydrogen network, where it is assumed that it is desirable to maximise the network efficiency (i.e. hydrogen demand / network distance). Clearly the choice of connection threshold affects the results in terms of the number of sites that will connect and a range of values were tested to establish the sensitivity. Figure 47 shows that the majority of potential network efficiency is reached with a threshold value of 50GWh/km. This value is used in lieu of more detailed cost-benefit analysis for different pipeline tiers, as would be carried out by gas networks.

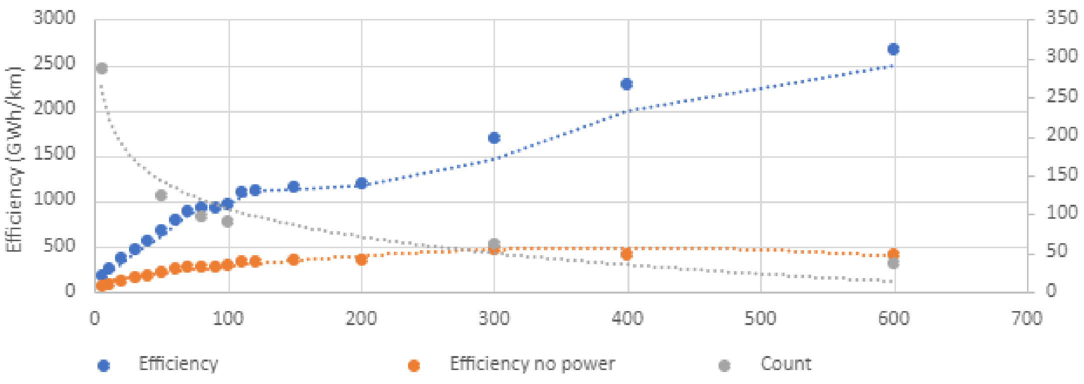

Figure 47 - Linear hydrogen demand density testing

B.1.5 Unsatisfied Hydrogen Demand

The creation of 'mini clusters' for green hydrogen production is assessed in the model as follows:

1. Identify one or more unconnected industrial sites that are judged to require hydrogen (i.e. from the industrial sectors used in Scenario 3) with an expected annual hydrogen demand of >40GWh (approximately equivalent to a 5MW electrolyser, i.e. a minimum capacity similar to the smallest planned projects in the Hub region and those that have applied for HAR funding)
2. Identify other nearby potential hydrogen demands that could form a mini cluster, based on a reasonable maximum radius

3. Estimate the total annual hydrogen demand of the mini cluster from the hydrogen model. For non-domestic sites that are included, assume an uptake factor of 50% (i.e. lower than in the bottom up method) to account for the likely price premium and uncertainty of offtakers
4. Estimate the size of electrolyser required

This method captures the largest and potentially most viable locations for additional green production. In each scenario a number of smaller unconnected industrial demands that are likely to require hydrogen remain; either individual sites or businesses where consumption is aggregated into the MSOA-level non-domestic data. These are not considered further in this study as they represent a small proportion of overall demand and the feasibility of small-scale electrolysis (or other means of hydrogen supply) would need to be considered for these locations on a site by site basis.

APPENDIX C - ECONOMIC ANALYSIS METHODOLOGY

To determine the investment required to achieve the modelled buildout of hydrogen assets and connection/conversion of consumer sites, results are extracted from the bottom-up model for each future year, for each scenario. These show the hydrogen assets built or converted in each year and are converted to a required investment with the high-level metrics shown in Table 17.

The peak hydrogen demand is used as a metric for power station and industry site conversions, as this reflects the scale of equipment to be converted. This is straightforwardly obtained for power stations, for industrial sites an assumed factor is used to estimate the peak demand based on the annual consumption

Table 17 - Economic analysis metrics

Hydrogen Asset Type	2024 Capital Cost
New production	£0.9m per MW output (large-scale blue & green) £1.1m per MW output (small-scale green, i.e. ≤ 25MW)
Distribution pipeline	£0.8m per km (newbuild) £0.2m per km (repurposed)
New storage	£0.1m per GWh capacity
Site conversion to hydrogen	£0.07m per MW peak demand (industry) £1.1m per MW peak demand (power)

Investment is assumed to occur in the construction sector, where each £1m of investment creates 12.5 direct and indirect jobs in the economy[44]. This estimate of total jobs created then requires a timeframe in which the investment takes place to provide context on the approximate number of jobs supported each year. This is a simplified approach to inform the roadmap, a Hydrogen UK study[45] provides an example of how economic analysis can be carried out in more detail across the hydrogen sector.

The total investment in hydrogen infrastructure and end-use conversion varies between scenarios. There are likely to be corresponding changes in the required regional investment in supporting or alternative technologies (e.g. CCUS or grid reinforcement). The net gain/loss of investment in the region due to changes in the expected development of hydrogen is therefore harder to quantify, and would require further study.

Key assumptions in the analysis are listed in the main body of the report, further points include:

- The employment assessment provides an indication of the full time jobs required to deliver, but does not consider ongoing jobs in operation, jobs that would be lost, or jobs transitioned from other parts of the existing energy industry. Further analysis is recommended in the action plan (see Section 7).
- The analysis does not evaluate lifecycle costs and therefore does not consider operating costs or replacement costs of the hydrogen assets

44 https://www.gov.scot/publications/input-output-latest/
45 Economic Impact of the Hydrogen Sector to 2030, Hydrogen UK, April 2024, Link

- Supporting economic activity occurring outside of the region is not quantified, such as manufacture of hydrogen vehicles, ships and planes (that would use hydrogen in the Hub region).
- The cost of supporting infrastructure (and associated jobs) is not explicitly considered, such as grid reinforcement, CCUS facilities to enable blue hydrogen etc. There is some overlap of this infrastructure with other decarbonisation pathways, so the additionality provided by hydrogen development is more difficult to determine.
- Hydrogen pipelines (e.g. phases of ECH) are assumed to have their construction spread out evenly between the start of construction and operational years. Hydrogen pipeline costs are not broken down at this stage between different pressure tiers.
- For hydrogen production, all investment is assumed to occur in the year that the asset becomes operational. This is clearly a simplification and produces a peak in required investment, but is used rather than making subjective estimates of investment profiles, which could vary significantly between projects and locations, as well as uncertainty in the operational dates. Further analysis is recommended in the action plan (see Section 7).
- For site conversions, it is assumed at this stage that conversions take place in the year that the technology becomes available. This again produces peaks in investment which would in reality be more spread out (e.g. where site assets may be replaced at end of life, rather than at the point of feasibility)

APPENDIX D - NEY HUB ACTION PLAN

Category	Ref	Action Description	Hub Role (Lead, Enable, Support)	Timeframe	Action Owner (to be determined)
Leadership/ Coordination	C1	Establish regular meetings of the Hub hydrogen working group. Develop terms of reference, identify funding and scope for action, as well as reviewing and formalising the actions included in this document, i.e. defining owners and initial tasks	Lead	Short Term (2024/25)	
	C2	Establish collaborative bid development/investment group in the Hub region and encourage participation in upcoming funding rounds (e.g. HAR3+) to reduce the risk of intra-Hub competition for limited funding, infrastructure etc.	Enable	Short Term (2024/25)	
	C3	Encourage stakeholder collaboration by promoting existing hydrogen/decarbonisation related workshops and groups in the NEY area - join up concurrent studies and initiatives (NB this is already part of the Hub's remit - but particular focus required given the need for development through to 2030)	Enable	Short Term (2024/25)	
	C4	Liaise and share lessons on 'live' hydrogen asset development with other clusters/Hubs - particularly in the next few years when significant change is expected. The timing of supply/demand is critical to ensure offtakers are available and there will be many lessons to be learned as first-of-a-kind projects begin. Assess markets and market failures to prioritise policy plan interventions	Lead	Short Term (2024/25)	
	C5	Develop coordinated/shared capacity building programme by promoting training and skills development and understanding needs across the Hub region. Increase awareness and demand uncertainty for supply chains. Work with industrial cluster and combined authorities to develop cooordinated plans.	Support	Short Term (2024/25)	
	C6	Encourage hydrogen asset developers to collaborate and share knowledge on requirements and developments in supporting infrastructure - e.g. grid connection applications, CCUS, hydrogen storage, road/rail connections and local planning	Enable	Short Term (2024/25)	
	C7	Liaise and engage with industry bodies and universities regarding research and innovation on key challenges for deployment in the Hub region	Enable	Short Term (2024/25)	
	C8	Engage with central government to inform national policies on certain issues: • Support deployment of CCUS infrastructure in wider Hub region • Develop business models and financial incentives for industrial fuel switching • Research/evidence gathering on hydrogen feasibility in different sectors and gaps in technology • Receive additional investment from Ofgem for infrastructure upgrades in the region. • Stricter industrial emissions regulations and carbon intensity targets/trajectories	Lead	Medium Term (2024-2029)	
Develop Evidence	E1	Related to Action C4 - identify first mover hydrogen projects or studies in the UK or abroad that can provide evidence on potential benchmark costs, timescales etc. and update the roadmap for the Hub region accordingly.	Lead	Medium Term (2024-2029)	
	E2	Develop economic analysis begun in the roadmap study to consider investment profiles for each type of project, map existing and required capacity of supply chain, workforce etc. to deliver on planned projects. Update this analysis regularly as evidence on costs and impacts of hydrogen projects becomes available and develops to build confidence in deployment extent and timescale	Enable	Short Term (2024/25)	
	E3	Independently assess supporting infrastructure (grid connections, CCUS, etc) to determine whether capacity and operation dates aligns with planned hydrogen infrastructure build-out. Liaise with developers and relevant bodies to align plans where possible, highlight pinch points and develop mitigations	Enable	Short Term (2024/25)	
	E4	Improve the understanding of which non-domestic sites (which make up a large proportion of current gas demand in the region) are likely to have a future hydrogen demand and improve the mapping of these sites compared to the current MSOA-level data	Enable	Short Term (2024/25)	
	E5	Further analysis and projection of hydrogen pricing and commercial attractiveness for consumers	Support	Short Term (2024/25)	
	E6	Establish regular (e.g. annual) review of hydrogen uptake estimates and how new technology or cost developments may affect routes to net zero for different sectors in the Hub region	Enable	Medium Term (2024-2029)	
	E7	Assess additional scenarios and sensitivity studies into other factors affecting hydrogen uptake in the region, to robustly identify no-regret actions and resilient pathways.	Lead	Medium Term (2024-2029)	
	E8	Determine criteria for hydrogen adoption at key sites that function as anchor points on the hydrogen distribution network in the region. Build on work already carried out by NGN and Cadent to identify thresholds for these sites with regards to price, timing, supply availability etc. Hold discussions with key example sites in the Hub region and identify common factors or concerns, engage with industry bodies	Enable	Short Term (2024/25)	
	E9	Support initiatives to conduct further mapping of hydrogen supply & demand at the local authority / combined authority level to develop greater confidence in the benefits and risks of hydrogen deployment across the Hub. Identify how the policy recommendations for WYCA could be read across to other LAs/CAs in the region	Enable	Short Term (2024/25)	
	E10	Conduct further work to improve resolution and profiling of supply/demand estimates to allow assessment of hydrogen storage and charge/discharge	Enable	Medium Term (2024-2029)	
	E11	Further assess the role of non-pipeline hydrogen distribution, e.g. road tankers for supplying smaller, isolated demands and the transport of hydrogen-based fuels to ports/airports	Lead	Short Term (2024/25)	
	E12	Modelling suggests an excess of production - conduct further study to determine whether there are credible routes that align with the expected timing of the supply and whether these can be supported to enable a positive feedback loop of development. Promote assessment of demand of neighbouring regions and wider UK.	Enable	Short Term (2024/25)	
	E13	Monitor local development at Bradford and other HAR1 / HAR2 projects to identify the feasibility and extent of supply from smaller, localised production plants, as potential examples of mini clusters and beginning a positive feedback in supply/demand	Lead	Medium Term (2024-2029)	
Support Hydrogen Deployment	D1	Develop understanding of where a UK or NEY Hub-based supply chain contributes to the deployment of hydrogen assets and how this could be developed further	Support	Medium Term (2024-2029)	
	D2	Assist businesses (with hydrogen demands) that are not expected to be part of the pipeline network. Initially make them aware of the potential lack of supply, then explore mitigations or alternatives as part of a credible net zero pathway (which may be hydrogen-based, or an alternative approach)	Enable	Medium Term (2024-2029)	
	D3	Remain engaged with government on hydrogen for heating trial. If it does happen, NEY region would be ideal starting point to roll out and benefit from skills development	Support	Short Term (2024/25)	
	D4	Continuous engagement with gas and electricity distribution and transmission networks to ensure they are considering needs for hydrogen development alongside other decarbonisation activities	Support	Long Term (2024-2034)	
	D5	Support Project Union and ECH which are key to the distribution of hydrogen (particularly inland) in the region. Understand key factors for each stage of ECH and ensure businesses and LAs on the pipeline route understand these	Support	Long Term (2024-2034)	
	D6	Encourage research in hydrogen technology for sectors with later projected adoption dates to bring this forward	Support	Medium Term (2024-2029)	
	D7	Encourage development of hydrogen storage in the Hub region to derisk new production projects or site conversions - research into potential sites and support during design/construction	Support	Medium Term (2024-2029)	
	D8	Produce (or share existing) impartial guidance document on use of hydrogen in different sectors to assist site owners. Reference government work and inform potential users within the region of decarbonisation options, with case studies of where hydrogen or others are already deployed	Lead	Medium Term (2024-2029)	