Department for
Business, Energy
& Industrial Strategy

# Hydrogen Transport and Storage Analytical Annex

Analytical Annex to the consultation on hydrogen transport and storage infrastructure

September 2022

Any enquiries regarding this publication should be sent to us at: hydrogenevidencebase@beis.gov.uk.

If you need a version of this document in a more accessible format, please email enquiries@beis.gov.uk. Please tell us what format you need. It will help us if you say what assistive technology you use.

# Contents

# Introduction

This annex summarises the evidence and analysis underpinning the hydrogen transport and storage consultation. Most of this annex is focused on transport and storage, however the consultation also covers strategic planning, regulatory frameworks, and blending.

The first section outlines the strategic context, including a future vision for the role of transport and storage. In the second section, current evidence on hydrogen transport and storage is collated - this includes the pipeline of current projects and an international comparison. The following two sections describe a Theory of Change for hydrogen transport and storage and analysis of the market barriers. In the last section, initial analysis underpinning Business Model design is summarised, including a proposed design framework. Taking the Theory of Change, market barriers, and business model design framework together, possible options for transport and storage business model design are suggested at the end of the last section.

# Strategic context

This section describes the current role of hydrogen transport and storage, possible technologies for transporting and storing hydrogen and gives an overview of the potential role of hydrogen transport and storage infrastructure in the future. More information is provided in the introduction to the main consultation.

Analysis by BEIS for CB6 suggests 250-460TWh of hydrogen could be needed in 2050, making up 20-35 per cent of UK final energy consumption[1]. Other pathways to net zero are possible, but these figures illustrate the potential scale of the hydrogen economy. Hydrogen transport and storage will be critical in enabling this growth with transport and storage infrastructure requirements depending on multiple factors. Transport needs depend on the location and volume of production, demand and storage. Storage needs will, in addition, depend on the types of production and demand, how fluctuating these are and the potential role of hydrogen in system balancing. There is some hydrogen produced in the UK currently, estimated to be approximately 10-27TWh/year[2]. This is mainly for use in large industrial processes where hydrogen is used in the same location as it is produced, meaning only limited pipelines and transport are needed. Current demand for hydrogen is also mostly constant and there is just one operational underground hydrogen storage site in the UK, with a capacity of 0.025TWh[3].

Hydrogen can be transported through pipelines - either via new-build infrastructure or there is the potential to repurpose existing gas pipelines for hydrogen. Research into the feasibility of using existing gas assets for hydrogen transport is ongoing[4]. Hydrogen can also be transported by road, rail, or ship and as a gas, liquid, or through a hydrogen carrier which increases the energy density. Ammonia (NH3), liquid organic hydrogen carriers (LOHCs, such as toluene), cryogenic liquid and substances such as metal hydrides are examples of hydrogen carriers.

Hydrogen can be stored either above-ground or underground. Examples of above-ground storage are specialist tanks or storage vessels, storing either liquefied or compressed hydrogen. These are suitable for storing MWh of energy and are already used in the chemicals industry and at hydrogen refuelling stations. Hydrogen can also be stored above-ground using hydrogen carriers, e.g., ammonia. Underground storage sites would provide larger capacity, storing energy in the magnitude of GWh and TWh. Hydrogen can be stored underground in e.g., salt caverns, created by ‘solution mining’ where water is used to dissolve an underground space in a seam of rock salt, allowing hydrogen to be piped in and out.

[1] https://www.legislation.gov.uk/ukia/2021/18/pdfs/ukia_20210018_en.pdf (Viewed on 28 June 2022)
[2] 10 TWh/year - DNV GL (2019), ‘Hy4Heat, Hydrogen Purity – Final Report’; 27 TWh.year - ERP (2016), ‘Potential Role of Hydrogen in the UK Energy System’ (Viewed on 28 June 2022)
[3] Please refer to the hydrogen transport and storage project pipeline section for more information on this storage site
[4] For example, National Grid’s Project Union (discussed in more detail in the project pipeline section) is undertaking research on repurposing of gas transmission pipelines

The British Geological Society advises that the UK has significant rock salt formations with potential for 1000s of terawatt hours of future storage[5].

This is a significant strategic advantage for the UK compared to many other countries. Hydrogen could also be stored under-ground in depleted oil and gas fields and there is ongoing research to test the feasibility of this. We will also need to consider competing storage demand, notably for CO2, in these fields. Other technologies for hydrogen storage are expected to be developed as research in this field progresses.

Storage vessels and transporting hydrogen by e.g., trailering will have lower upfront costs than other methods and are quicker to install or deploy making them more suitable for smaller volumes of hydrogen. These solutions may therefore be attractive for initial hydrogen production projects. Transporting hydrogen by pipeline and storing hydrogen underground will likely be the most efficient and cost-effective solution for large volumes of hydrogen. This larger infrastructure however has higher upfront costs and longer lead-in times. We expect these technologies to be deployed as the hydrogen economy grows.

As the hydrogen economy develops, hydrogen transport that links together industrial clusters will connect more sources of supply and demand. This will contribute to a liquid and competitive hydrogen market. Without connecting hydrogen transport, extra production and storage may be required in certain locations to meet demand fluctuations.

**Curtailment** is a purposeful reduction in electricity output. Curtailment occurs for two main reasons:

1. Oversupply – there is not enough demand for the electricity that could be produced due to e.g., high wind speeds
2. Transmission constraints – there isn’t enough transmission infrastructure to transport the electricity to useful demand

Hydrogen storage could play an important role in supporting whole energy system balancing and help us achieve a fully decarbonised low-cost power sector. Storing hydrogen produced by electrolysis at times of excess renewable electricity production will reduce curtailment. In the Energy Security Strategy[6], we doubled our UK ambition for hydrogen production up to 10GW by 2030 (subject to affordability and value for money), with at least half of this from electrolytic hydrogen. The drive on renewables - notably to deliver up to 50GW of offshore wind by 2030 – makes potential storage of green hydrogen especially valuable. As outlined in the hydrogen section of the Energy Security Strategy, excess renewable electricity could be used to produce hydrogen which would be stored and used to power the grid when

[5] Williams J and others, British Geological Survey (2020), ‘Theoretical capacity for underground hydrogen storage in UK salt caverns’ (viewed 21 June 2021)
[6] https://www.gov.uk/government/publications/british-energy-security-strategy/british-energy-security-strategy (Viewed on 6 June 2022)

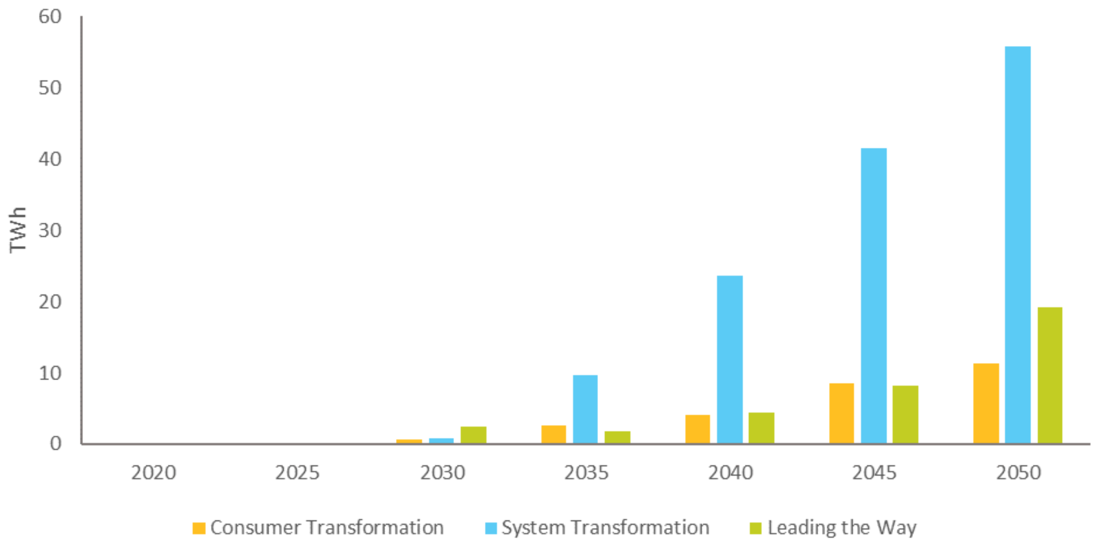
needed. Analysis by AFRY estimates that long duration energy storage, supplied predominantly by hydrogen[7], could provide between £13-24bn savings to the electricity system between 2030 and 2050 – by reducing network constraints and seasonal imbalances emerging from an increasingly weather-driven system. The savings are predominantly driven by reduced fuel costs for generators. The analysis assumes hydrogen storage infrastructure is already built and so does not include the costs associated with this, nor the costs of de-risking necessary technologies[8].

There are a variety of estimates of storage requirements, which are revised and updated as the evidence base grows. National Grid ESO publish annual Future Energy Scenarios representing a range of decarbonisation pathways. In all net zero scenarios, hydrogen storage is predicted to be needed from 2030 onwards. By 2035, at least 2TWh of hydrogen storage is required as hydrogen generation, especially by electrolysis, grows[9].

In 2050, FES estimates a maximum of 56TWh of hydrogen storage will be needed in their System Transformation scenario (Figure 1). In this scenario, there is high use of hydrogen for heating and inter-seasonal hydrogen storage is required in addition to hydrogen storage for system balancing. Aurora Energy Research's 'Hydrogen for a Net Zero GB' report concludes that 19TWh of centralised salt cavern storage might be required by 2050[10]. Modelling for the 2050 System Transformation FES estimates assumes that hydrogen produced from natural gas (blue hydrogen) does not ramp up and down in response to changes in seasonal demand as it is assumed that these plants operate most efficiently at baseload. This means the need for storage is higher than in a scenario where blue hydrogen production does respond to changes in demand and partly explains why FES estimates are higher than e.g., Aurora's estimate of required storage.

[7] Multiple assets are required to enable hydrogen to power. These include hydrogen production (e.g., electrolysis), hydrogen storage (e.g., salt caverns) and H2 to power generators (e.g., hydrogen CCGTs).
[8] Please refer to the original analysis for more information and details on the methodology: https://www.gov.uk/government/publications/benefits-of-long-duration-electricity-storage (Viewed on 4 August 2022)
[9] https://www.nationalgrideso.com/document/263951/download (Viewed on 26 July 2022)
[10] https://auroraer.com/insight/hydrogen-for-a-net-zero-gb/ (Viewed on 6 June 2022)

**Figure 1: FES Hydrogen Storage Capacity Requirements in 3 net zero scenarios[11]**




The capacity of hydrogen storage required is mainly predicted by the hydrogen demand of each of the three scenarios modelled in FES. The consumer transformation scenario predominantly relies on electrification and energy efficiency to decarbonise and has the lowest hydrogen demand and therefore hydrogen storage. System transformation has the greatest hydrogen demand, including hydrogen for use in heating. This scenario therefore has the greatest inter-seasonal variation, with stored hydrogen peaking in mid-autumn and declining through winter as hydrogen heat demand increases. The Leading the Way scenario has lower heating requirements from hydrogen and overall lower hydrogen demand than System Transformation, resulting in lower storage requirements and lower inter-seasonal variation.

The UK currently has seven salt caverns and depleted gas fields being used as active natural gas storage facilities, providing approximately 1.5 billion cubic meters, or 16TWh, of storage capacity[12]. Although some of this could be repurposed for hydrogen storage, providing the same level of energy storage for hydrogen would require greater capacity given that hydrogen has only a third the energy density of natural gas. A recent study indicated that there is a theoretical capacity of up to 3000TWh of hydrogen storage in the UK, although if small sites are discounted, this drops to 200TWh[13].

[11] https://www.nationalgrideso.com/document/263876/download (Viewed on 26 July 2022)
[12] https://www.ofgem.gov.uk/system/files/docs/2021/01/2021_gas_storage_data_0.pdf (Viewed on 6 June 2022)
[13] https://ukccsrc.ac.uk/wp-content/uploads/2020/05/John-Williams_CCS-and-Hydrogen.pdf (Viewed on 6 June 2022)

# Hydrogen transport and storage evidence

In this section, the pipeline of proposed transport and storage projects is summarised to give an idea of potential hydrogen transport and storage growth in the UK. An international comparison of hydrogen transport and storage follows, providing a global picture and additional context for work in the UK.

## Hydrogen transport and storage project pipeline

The two maps in this section (Figures 2 and 3) show some of the potential GB transport and storage infrastructure projects currently in the public domain. These projects are proposals by companies and are not based on government planning or analysis. Further analysis will be needed to assess how much transport and storage infrastructure will be required, including when and where this should be. As our evidence base grows, the hydrogen economy develops and the scale and location of the end uses of hydrogen become more certain, this will allow more informed assessments of necessary projects and their timelines for construction, initial use, and operation at higher capacities. Regulatory and policy changes, considered throughout the consultation, will be critical for these projects to be realised. Additionally, these projects are all in early development stages and therefore, not all projects will necessarily go ahead or be delivered to the proposed timelines.

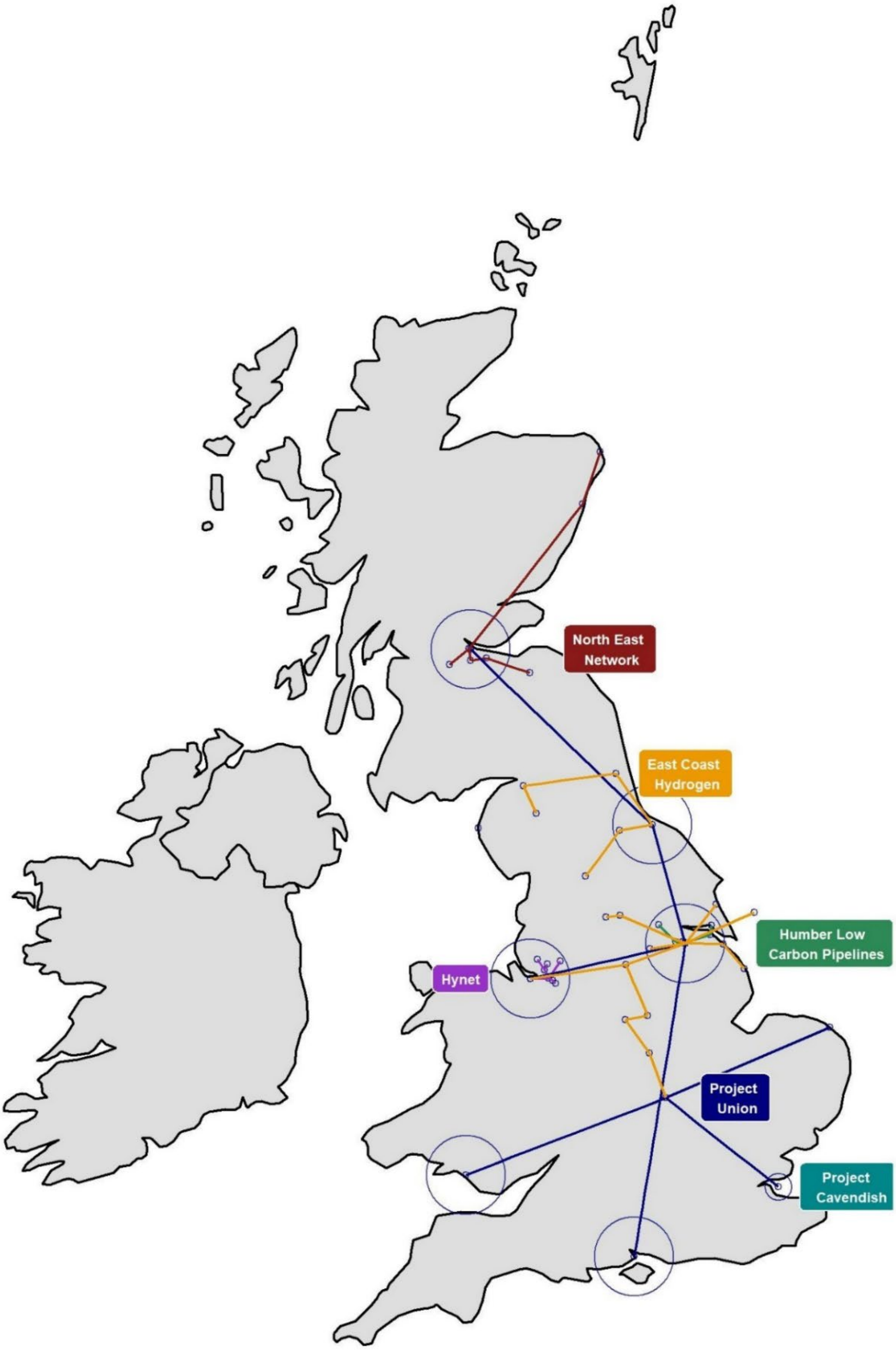
For hydrogen transport, the first map shows potential pipelines (either new build or repurposed) detailed in these projects' plans. Projects have scoped potential growth in varying detail e.g., East Coast Hydrogen have already published detailed plans for a possible expansion outside of the Northeast industrial clusters in later phases of their project. These projects would be sequenced in line with hydrogen production and demand growth, with construction of the initial stages of projects and localised network plans starting sooner. Earlier projects could include, for example, the Teesside and Humberside cluster connection in Project Union and the more localised network projects within clusters – Hynet and Humber Low Carbon Pipelines.

The hydrogen transport and storage infrastructure projects in the sections below are not an exhaustive list – there will be some projects which BEIS aren't aware of and not all projects are in the public domain. The majority are proposals, mainly in the feasibility study stage and the scope of the plans (particularly later stages) may change depending on the growth of the wider hydrogen economy and decisions on e.g., heating and blending. Production projects with some transport and storage infrastructure planned are not included in this section which focuses on specific, stand-alone transport and storage infrastructure. Initial contracts awarded through the production Hydrogen Business Model may provide some price support for small-scale transport and storage, if this infrastructure is assessed as being necessary, affordable, and providing value for money[14]. We are likely to see proposals for small-scale transport and storage infrastructure emerge as the first contracts for the production Hydrogen Business Model are allocated. Similarly, this pipeline focuses on infrastructure projects, so does not include research projects associated with hydrogen transport and storage. The investor roadmap[15] published by BEIS includes a sample of hydrogen projects across the value chain.

[14] https://www.gov.uk/government/consultations/design-of-a-business-model-for-low-carbon-hydrogen (Viewed on 7 July 2022)
[15] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1067408/hydrogen-investor-roadmap.pdf (Viewed on 23 May 2022)

## Transport

**Figure 2: Map of proposed hydrogen pipelines[16]**




[16] The projects and pipelines mapped here are those projects which have published specific geographical information on network growth. Project Cavendish has plans for potential hydrogen transport into and across London and the South-East.

The hydrogen transport projects mapped in Figure 2 and summarised below are proposals by current gas network operators. These projects aren't a definitive list but provide examples of published plans with specific geographical information on network growth. There are additional projects, e.g., the Southampton cluster[17] and Capital Hydrogen[18] which are infrastructure related, but these projects are in their early stages and plans for any network growth are still being developed. Hydrogen transport projects included here are all to transport hydrogen by pipelines – either new build pipelines or repurposed natural gas pipelines. Hydrogen can also be transported by e.g., trailering or shipping. We could expect more planned projects, outside of those proposals by gas network operators, where hydrogen is transported using other technologies.

The projects mapped above have all started early development work – the proposed locations, timelines and work done to date are summarised below. Gas network operators are monopoly companies, regulated by Ofgem. These companies have started some limited early development work on H2 networks under the current price control arrangements. Enduring commercial arrangements for hydrogen transport projects are consulted on for the first time in the corresponding consultation, please refer to the transport chapter for more details.

A **feasibility study** is an assessment of the practicality of a proposed plan or project. An intermediate stage building on the feasibility study is sometimes referred to as **pre-FEED**. The **Front-End Engineering Design (FEED)** stage follows the feasibility study and basic engineering studies are conducted to explore technical issues and estimate project costs. A **Development Consent Order (DCO)** is an application for consent to the Planning Inspectorate.

[17] https://www.sgn.co.uk/about-us/future-of-gas/southampton-water (Viewed on 12 July 2022)
[18] Not mapped or included below is a project called Capital Hydrogen, launched in April 2022 by SGN. The study in its early stages and will first scope the hydrogen potential in London and the Southeast: https://sgn.co.uk/news/london-study-kick-start-hydrogen-vision-capital-support-of-net-zero-carbon-target (Viewed on 13 June 2022)

**Project Union – National Grid[19]**

| | |
|---|---|
| Proposed location | The project is exploring a hydrogen transmission backbone connecting industrial clusters across Great Britain. This will be done in a phased approach, with the first phase looking to connect the Teesside and Humberside clusters. |
| Planned timelines | Project Union plans to progress as the clusters develop. The government has committed to deploying CCUS in a minimum of two industrial clusters by the mid-2020s, and four by 2030 at the latest[20]. |
| What has been done so far? | National Grid have started the feasibility stage of Project Union. This stage includes identifying pipeline routes, assessing the readiness of existing gas assets, and determining a transition plan for assets. |

**East Coast Hydrogen – National Grid, Cadent and Northern Gas Networks[21]**

| | |
|---|---|
| Proposed location | The proposed first stage of the project is the Teesside to Humber connection (interlinked with the first phase of Project Union). The next step (phase 2) planned is growth into Yorkshire and East Midlands, and possibly expansion into Northern urban areas and the Midlands. A later stage could include expansion into Scotland and connecting with e.g., the Hynet project. |
| Planned timelines | First stage - 2024-2030, phase 2 - 2028-2037, later stages 2032 and beyond |
| What has been done so far? | East Coast Hydrogen have completed their feasibility study to assess the practicality of the project. |

[19] https://www.nationalgrid.com/stories/journey-to-net-zero-stories/making-plans-hydrogen-backbone-across-britain (Viewed on 23 May 2022)
[20] https://www.gov.uk/government/publications/cluster-sequencing-for-carbon-capture-usage-and-storage-ccus-deployment-phase-1-expressions-of-interest/october-2021-update-track-1-clusters-confirmed (Viewed on 23 May 2022)
[21] https://www.nationalgrid.com/uk/gas-transmission/document/138181/download (Viewed on 23 May 2022)

### Hynet – Cadent[22]

| | |
|---|---|
| Proposed location | Part of the HyNet low carbon cluster in the Northwest to deliver hydrogen to multiple industrial users and power generators in the region. |
| Planned timelines | Following the build of the hydrogen production plant at Stanlow, Cadent anticipates starting construction activities on the first part of the hydrogen network from 2025. |
| What has been done so far? | The Industrial Strategy Challenge Fund[23] contributed £19.5m towards the Hynet onshore project[24] for hydrogen and CCUS. This project includes CCUS infrastructure so some of this funding will be for the $CO_2$ network in addition to hydrogen transport. Ofgem provided £12m for the FEED study through the RIIO-2 natural gas network price control[25], as the project was strategically important to create evidence to make a policy decision around the use of hydrogen, while also laying the foundation for the future decarbonisation of an industrial cluster in the northwest of England. |

### Humber Low Carbon Pipelines – National Grid Ventures[26]

| | |
|---|---|
| Proposed location | Local hydrogen transport within the Humber region. |
| Planned timelines | The project plans to submit their DCO application late 2022 and start construction in 2024. |
| What has been done so far? | Zero Carbon Humber received £75m from the ISCF[27,28], some of which is for Humber Low Carbon Pipelines alongside funding for the production aspect of the project. The FEED study for this project is ongoing. |

[22] https://www.hynethydrogenpipeline.co.uk/ (Viewed on 23 May 2022)
[23] The Industrial Strategy Challenge Fund (ISCF) is designed to address the big societal challenges faced by UK businesses. The fund is backed by £2.6 billion of public money, with £3 billion in matched funding from the private sector.
[24] https://www.ukri.org/news/ukri-awards-171m-in-uk-decarbonisation-to-nine-projects/ (Viewed on 23 May 2022)
[25] RIIO-2 is the second set of price controls implemented under Ofgem's RIIO model (Revenues = Incentives + Innovation + Outputs) and spans 2021-2026 for the natural gas transmission and distribution network companies. RIIO enables investment in network assets for natural gas and electricity network companies in GB.
[26] National Grid Ventures is the competitive division of National Grid plc and operates outside of National Grid's core regulated businesses.
[27] https://www.nationalgrid.com/our-businesses/national-grid-ventures/humber-low-carbon-pipelines (Viewed on 23 May 2022)
[28] https://www.zerocarbonhumber.co.uk/news/the-road-to-net-zero-starts-in-the-humber/ (Viewed on 23 May 2022)

### North East Network – SGN[29]

| | |
|---|---|
| Proposed location | The first phase plans to link Aberdeen and St Fergus followed by pipelines between industrial sites around Grangemouth. The planned next phase would link Aberdeen and Grangemouth. |
| Planned timelines | Under current plans, North East Network plan to start the first phase of construction in 2024, the second phase in 2025 and the third phase in 2026/27. |
| What has been done so far? | SGN spent £1,018,000 from RIIO-2 NIA innovation funding on the pre-FEED for this project[30,31]. |

### Project Cavendish - SGN[32]

| | |
|---|---|
| Proposed location | Isle of Grain - no specific hydrogen pipe/location planned yet, currently the projects plan is to blend or inject hydrogen into a repurposed gas grid. |
| Planned timelines | By 2026 the project aims for hydrogen to be produced and flowing. |
| What has been done so far? | SGN spent £425,000 from RIIO-2 NIA innovation funding on the feasibility study[33]. |

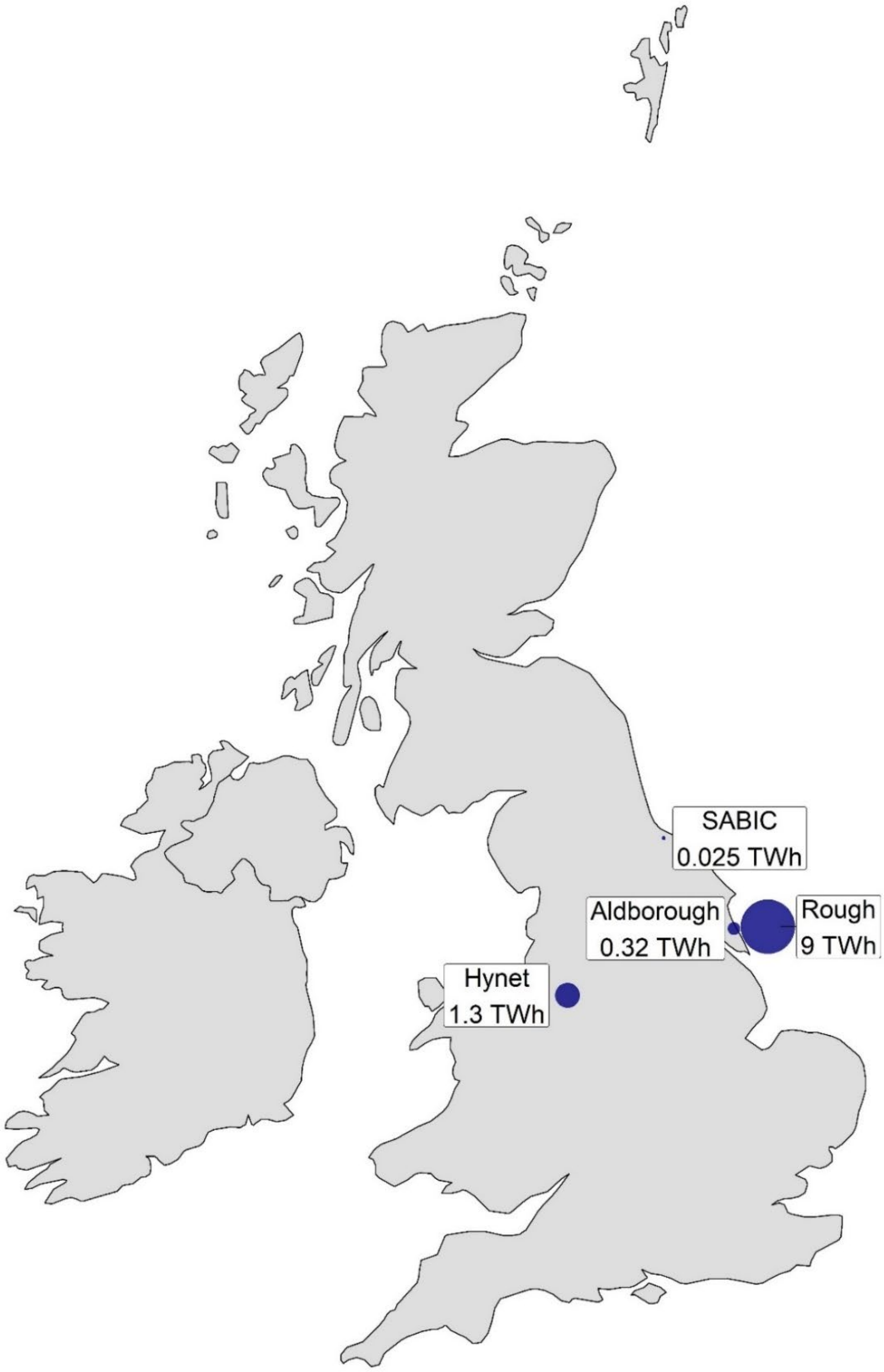
The proposals outlined above are for some specific infrastructure projects. Network operators have also spent money on research and testing projects, including projects to build the evidence base on the potential to repurpose natural gas pipelines for hydrogen. The Energy Networks Association's (ENA) database compiles information on network innovation projects[34], including those relating to hydrogen.

[29] https://sgn.co.uk/about-us/future-of-gas/ne-network-industrial-cluster (Viewed on 23 May 2022)
[30] https://smarter.energynetworks.org/projects/nia2_sgn0007/ (Viewed on 23 May 2022)
[31] In the RIIO-2 price control, the Network Innovation Allowance (NIA) provides limited funding to networks to enable them to take forward innovation projects that have the potential to deliver longer-term financial environmental benefits for consumers and/or address consumer vulnerability, which they would not otherwise undertake within the price control.
[32] https://www.projectcavendish.com/ (Viewed on 23 May 2022)
[33] https://smarter.energynetworks.org/projects/nia_nggt0143 (Viewed on 23 May 2022)
[34] https://smarter.energynetworks.org/ (Viewed on 23 May 2022)

## Storage

**Figure 3: Map of proposed hydrogen storage projects and potential capacity[35]**

*SABIC in Teesside is in operation, the other 3 projects are plans for potential hydrogen storage projects*




[35] The size of the points aims to represent the magnitude of capacity available in different storage sites. However, to ensure all points can be viewed, these are not exactly to scale.

There are three planned underground GB hydrogen storage projects in the public domain, described below. Subject to commercial and regulatory certainty, these projects could be operational from the late 2020s onwards. In addition, and included on the map above, there is one hydrogen storage site already in operation in the UK. This is a salt cavern site in Teesside which has been in operation since the 1970s[36]. SGN is currently working on a project to produce a database of geological hydrogen storage potential in the UK[37].

| Project | Site | Capacity | Location |
|---|---|---|---|
| Rough – Centrica | Depleted gas field | Up to 9TWh | Off the East Yorkshire Coast |
| Aldborough – SSE | Salt cavern | Up to 320GWh | Hull |
| Hynet – INOVYN | Salt cavern | Up to 1.3TWh | Northwich, Cheshire |

None of the above storage infrastructure projects have received any public funding so far. BEIS has supported storage research projects, for example HySecure[38] which demonstrated the deployment of grid-scale storage of hydrogen in a salt cavern.

[36] http://hyunder.eu/wp-content/uploads/2016/01/D3.1_Overview-of-all-known-underground-storage-technologies.pdf (Viewed on 23 May 2022)
[37] https://smarter.energynetworks.org/projects/nia2_sgn0013/ (Viewed on 23 May 2022)
[38] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/866376/Phase_1_-_Inovyn_-_HySecure.pdf (Viewed on 23 May 2022)

# International transport and storage comparison

Hydrogen is an emerging energy source worldwide. All countries acknowledge that they need more information and more time to develop their hydrogen economy plans, including hydrogen transport and storage. Although the level of detail varies, most strategies are a description of a government's plan to plan. For hydrogen transport and storage specifically, a lot of countries state that commercial and regulatory frameworks need to be developed.

Few countries already have any dedicated hydrogen transport and storage public funding or commercial arrangements. Across almost all countries, planning for hydrogen transport funding is further on than hydrogen storage. This is because most countries have existing gas networks that could be repurposed for hydrogen. Because these assets exist, the challenge of how to manage and fund the potential conversion of these is being tackled and discussed already.

**Transport and storage growth**

The deployment of hydrogen transport and storage infrastructure will diverge depending on countries' transport and storage needs, government interventions and market forces. A high-level view of the potential future role of transport and storage in the UK is provided in the first section of this annex and the introduction to the consultation. Research on hydrogen transport and storage, commissioned by BEIS, has also been published alongside this consultation. This research provides possible growth scenarios for hydrogen transport and storage in the UK.

Small-scale transport and storage infrastructure does not have a strict definition and 'small-scale' could describe several attributes. Small-scale can include infrastructure designed to transport or store smaller volumes of hydrogen e.g., storage in above-ground hydrogen tanks versus storage in large salt caverns. For hydrogen transport, small-scale could refer to the distance hydrogen is being transported, rather than the volumes transported – for example, if hydrogen is transported through a short pipeline on a single industrial site versus a longer pipeline connecting two different sites. Small-scale could also refer to whether transport or storage is linked to e.g., one specific hydrogen producer or end-user versus larger-scale transport and storage infrastructure which could service many producers and users.

Although not directly related to specific infrastructure or projects, the high-level phrases 'small-scale' and 'larger-scale' are useful to describe the different types and phases of hydrogen transport and storage growth we could see.

Projections of hydrogen transport and storage growth differ across the world. The roll out of transport and storage infrastructure in different countries will impact their funding priorities. Canada[39] and Germany[40] for example, are focused on the 'end-game' of the hydrogen economy and their priority is to enable the building of larger-scale infrastructure from the start. Germany states their infrastructure plans should be geared towards a 2050 demand scenario now, with the aim to minimise stranded assets and accelerate the growth of production and demand[40].
In the UK, whether hydrogen will be used widely in heating will affect the magnitude of hydrogen demand and hydrogen distribution requirements. The UK plans to make the decision on hydrogen use in heating in 2026, whereas Canada[39], for example, has already identified hydrogen use in heating as a priority. In contrast to the 'end-game' approach, some countries (including the UK, Finland[41] the Czech Republic[42]) outline the need for small-scale transport and storage solutions to enable the growth of a hydrogen economy. These countries think larger scale transport and storage will follow, as production and demand increases. In the UK, the scope of larger scale transport and storage will be affected by the planned decision on hydrogen in heating in addition to the growth of hydrogen demand in the industry, power, and transport sectors.

Hydrogen production, demand, transport, and storage are all interlinked, and the growth of the hydrogen economy at any scale needs infrastructure across the value chain. However, countries differ in their position on whether transport and storage need to be built first or if production or demand should be the frontrunners. The UK's position is that initial transport and storage is likely to be small-scale linked to production (e.g., above ground storage and on-site industrial pipelines), with systematic and enabling larger-scale infrastructure to follow. The Netherlands[43] position (and the EU's[44] more broadly) is that transport and storage needs to be built and hydrogen demand will then follow.

Countries with lots of renewable electricity production capacity, for example Paraguay[45] which has substantial hydroelectric capacity, are especially focused on how hydrogen storage can be used to balance this supply. As the hydrogen would mainly be converted back to electricity, their focus is on hydrogen storage infrastructure rather than extensive hydrogen transport. Some countries e.g., Australia[46] are focused on exporting hydrogen rather than using it domestically. Countries who plan to export hydrogen rather than use it themselves will probably not need as complex domestic transport and storage solutions as those envisaged in parts of Europe, for example.

[39] https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf (Viewed on 4 June 2022)
[40] https://www.bmwi.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.pdf?__blob=publicationFile&v=6 (Viewed on 4 June 2022)
[41] https://www.businessfinland.fi/4abb35/globalassets/finnish-customers/02-build-your-network/bioeconomy--cleantech/alykas-energia/bf_national_hydrogen_roadmap_2020.pdf (Viewed on 4 June 2022)
[42] https://www.mpo.cz/assets/cz/prumysl/strategicke-projekty/2021/9/Hydrogen-Strategy_CZ_2021-09-09.pdf (Viewed on 4 June 2022)
[43] https://www.government.nl/documents/publications/2020/04/06/government-strategy-on-hydrogen (Viewed on 4 June 2022)
[44] https://energy.ec.europa.eu/select-language?destination=/node/1 (Viewed on 4 June 2022)
[45] https://www.ssme.gov.py/vmme/pdf/H2/DIGITAL_ENG_H2_Marco_Conceptual.pdf (Viewed on 4 June 2022)
[46] https://www.industry.gov.au/sites/default/files/2019-11/australias-national-hydrogen-strategy.pdf (Viewed on 4 June 2022)

Some countries (e.g., Japan[47]) are focused on using hydrogen in the transport sector. Although, this will require extensive refuelling stations, the transport infrastructure needed will be very different to using hydrogen in heating, for example. A small number of countries (including Slovakia[48] and Sweden[49]) have highlighted that the electricity grid may need to be developed to enable the production of electrolytic hydrogen and that this needs to be considered in parallel with the development of a hydrogen network or the conversion of the natural gas network to hydrogen.

### Repurposing of gas networks

Countries with gas networks, and gas network operators themselves, are considering whether these networks can be repurposed for hydrogen transport. Most countries have flagged that new regulation is required for this. Some countries are already considering how this transition will be managed. A few countries - especially in the EU (e.g., Belgium[50], Czech Republic[42], and Germany[40]) – have already made strong statements that their incumbent gas network operators will be partnered with government to build and repurpose the existing gas network for hydrogen.

In December 2021, the EU proposed detailed legislative changes for gas and hydrogen network regulation[51]. This is by far the most comprehensive plan for regulatory changes. Broadly, their proposal is that although in principle hydrogen users should pay for the hydrogen network, costs can be socialised between gas and hydrogen users at first. This would be via a Regulated Asset Base (RAB). RAB's are explained further in the final section of this annex on Business Model design. The EU proposes that hydrogen activity and financing will need to be recorded separately from the start allowing the hydrogen RAB to be split off from the natural gas RAB in the future.

Only two countries – the Netherlands[52] and Germany[53] – have approved plans by gas network operators to fund the capital costs of gas pipeline conversion. As described in the previous section, gas network operators in the UK have started limited early development work on hydrogen transport infrastructure. However, the UK to date has not approved any capital funding for construction work, which the Netherlands and Germany have. In March 2021, the German regulator approved 12 hydrogen pipeline plans from their incumbent gas network operators. This will be funded via their current financing arrangements (the natural gas RAB) to enable work to start quickly. The regulator has stated that these hydrogen projects need to

[47] https://www.meti.go.jp/english/press/2019/pdf/0312_002b.pdf (Viewed on 4 June 2022)
[48] https://www.economy.gov.sk/top/slovensko-ma-vlastnu-narodnu-vodikovu-strategiu (Viewed on 4 June 2022)
[49] https://www.energimyndigheten.se/remissvar-och-uppdrag/Download/?documentName=F%C3%B6rslag%20till%20nationell%20strategi%2025%20nov.pdf&id=1793 (Viewed on 4 June 2022)
[50] https://www.jdsupra.com/legalnews/the-belgian-federal-hydrogen-vision-and-7600748/ (Viewed on 4 June 2022)
[51] https://energy.ec.europa.eu/topics/markets-and-consumers/market-legislation/hydrogen-and-decarbonised-gas-market-package_en (Viewed on 4 June 2022)
[52] https://www.bloomberg.com/news/articles/2022-01-20/the-netherlands-bets-on-hydrogen-after-natural-gas (Viewed on 4 June 2022)
[53] https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/DE/2022/20220120_SR_Gas.html?nn=265778 (Viewed on 4 June 2022)

be accounted for to enable them to be separated later and the details of this will need to be arranged. At the start of 2022, the Netherlands committed to funding one project by their state-owned gas network operator. This is stand-alone and comes before any other commercial arrangements.

Potential repurposing of the gas network in the UK is explored in the transport chapter of the consultation. Further, some of the projects described in the pipeline section are progressing work to provide evidence on the feasibility of repurposing UK gas networks for hydrogen, e.g., Project Union[19].

## Funding

Apart from the commitments by the Netherlands and Germany (described above) to fund gas network projects, there are no specific or national hydrogen transport and storage funding mechanisms for capital or operating spend e.g., a hydrogen transport or storage business model.

This consultation is the first external engagement by the UK on transport business models and storage business models. A design framework and possible options are discussed in the last section of this annex. Proposals and options for transport and storage business models are consulted on in the transport chapter and storage chapter of the main consultation.

Several countries including the UK and e.g., Japan have already funded hydrogen transport and storage research and development. In some countries (e.g., Portugal[54]), investment in storage is paired with investment in specific production plants, rather than a specific storage investment arrangement. Some countries, for example Finland, have wider renewable energy investments schemes with government funding in place[55] but these aren't targeted at hydrogen or hydrogen transport and storage specifically.  South Korea has committed a lot of government funding to the hydrogen economy, including some hydrogen transport and storage projects[56]. This is project specific funding rather than a national mechanism to support e.g., all future transport and storage projects.

In those countries where small-scale transport and storage is predicted to be needed to enable the growth of the hydrogen economy (e.g., Czech Republic, Finland), there is no proposed arrangements for funding this. The UK however has stated that small-scale transport and storage costs could be supported in initial production Hydrogen Business Model contracts, the Net Zero Hydrogen Fund (NZHF) and the Renewable Transport Fuel Obligation (RTFO).

The EU has proposed detailed legislative changes[51] and their proposed plans means that hydrogen network costs could be socialised between gas and hydrogen consumers. However, these proposals mainly cover how funding is accounted for. Any additional funding that may be needed on top of natural gas RAB cost

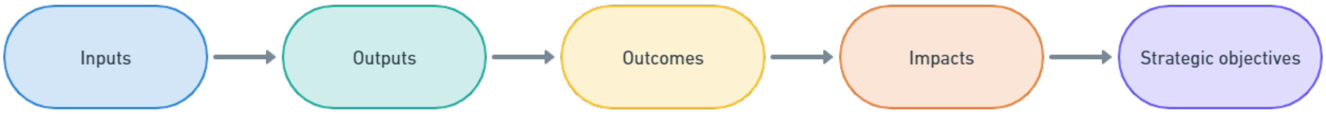
[54] https://participa.pt/contents/consultationdocument/Estrate%CC%81gia%20Nacional%20para%20o%20Hidroge%CC%81nio%20DRAFT%20publicac%CC%A7ao.pdf (Viewed on 4 June 2022)
[55] https://tem.fi/en/first-application-round-for-energy-investment-subsidies (Viewed on 4 June 2022)
[56] https://www.bnef.com/insights/27081/view (Viewed on 4 June 2022)

mutualisation aren't covered in the EU's proposal, as this would be down to Member States.

# Theory of Change

In this section, a proposed Theory of Change is outlined for hydrogen transport and hydrogen storage. This uses the Theory of Change approach set out in the BEIS monitoring and evaluation framework[57] and shown in Figure 4 below. The approach can be used to understand what is needed to overcome barriers and deliver the transport and storage vision described in the first section and broader strategic objectives.

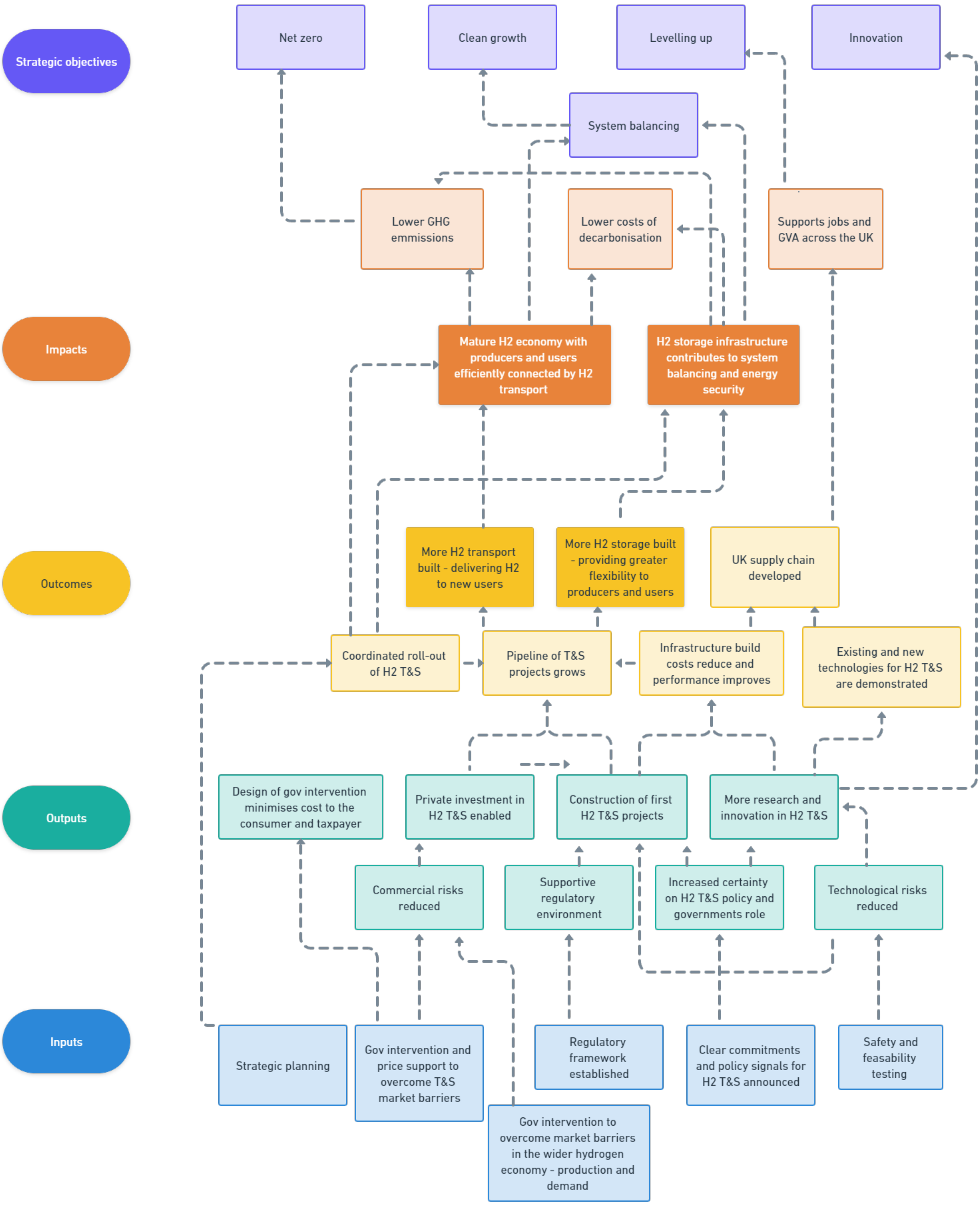
**Figure 4: Theory of Change framework**




Market barriers for hydrogen transport and storage are considered in more detail in the next section. Taken together, the Theory of Change and market barriers analysis can be used as a starting point to understand what actions and policies will be needed for the growth of hydrogen transport and storage. Both the barriers and Theory of Change for hydrogen transport and storage will change as the hydrogen economy grows and if desired outcomes change as the hydrogen market develops.

[57] https://www.gov.uk/government/publications/beis-monitoring-and-evaluation-framework (Viewed on 20 June 2022)

## Figure 5: Theory of Change for hydrogen transport and storage



### Inputs

Government intervention and price support to overcome market barriers for transport and storage are proposed to be delivered via Business Models (described further in the next section). The initial design options for these is consulted on in this publication. This could include support for upfront development costs, capital costs and ongoing revenue support. The regulatory framework and role of strategic planning are also key inputs consulted on for the first time here. The consultation itself and related Government publications e.g., Energy Security Strategy, Hydrogen Strategy[58], and future consultations on hydrogen transport and storage, will provide clear and consistent messaging of the overarching transport and storage policy. Outside of this publication, BEIS are also supporting industry with safety and feasibility testing of different transport and storage technologies[59].

There are supporting activities outside this Theory of Change in the wider hydrogen economy which will be needed to deliver these objectives and the future vision for transport and storage, described in the first section. Notably, these include support for hydrogen production through the production Hydrogen Business Model and NZHF and potential end use switching support, e.g., plans for hydrogen ready boilers[60]. Inputs in the wider supply chain will increase the demand for hydrogen transport and storage, reduce uncertainties around future supply and demand and therefore reduce risks associated with transport and storage. Figure 10 in the analytical annex for the hydrogen strategy[61] provides a Theory of Change for the whole hydrogen economy.

### Outputs

Proposed government intervention and support delivered by business models will reduce the commercial risks of transport and storage projects and stimulate private investment in transport and storage. Effective design of business models will also minimise costs to the consumer and/or taxpayer. This will enable construction of the first larger-scale transport and storage projects. A supportive regulatory environment and increased certainty around hydrogen transport and storage and wider hydrogen policy will also reduce risks and contribute to the construction of hydrogen transport and storage projects. Safety testing will decrease the technological risks associated with transport and storage projects, allowing more infrastructure to be built. Initial safety testing and a developing market for hydrogen transport and storage will also lead to more research and innovation in transport and storage technologies and deployment.

---

[58] https://www.gov.uk/government/publications/uk-hydrogen-strategy (Viewed on 20 June 2022)
[59] For example, details of hydrogen safety and feasibility projects in progress and completed by energy networks can be found on the Energy Networks Association Smarter Networks Portal: https://smarter.energynetworks.org/
[60] https://www.gov.uk/government/consultations/enabling-or-requiring-hydrogen-ready-industrial-boiler-equipment-call-for-evidence (Viewed on 20 June 2022)
[61] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011499/Hydrogen_Analytical_Annex.pdf (Viewed on 20 June 2022)

### Outcomes

Strategic planning is likely to be a key input for the coordinated roll out of hydrogen transport and storage. BEIS' initial position on the role of strategic planning is covered in the corresponding chapter of this consultation. Momentum and learning following the first transport and storage projects, will mean the pipeline of transport and storage projects grows. The development and deployment of first of a kind (FOAK) projects will reduce costs and improve performance. In turn this will contribute to the growth in the number of transport and storage projects. As existing and new technologies for hydrogen transport and storage are demonstrated (facilitated by research and innovation) a UK supply chain will develop. As more hydrogen transport infrastructure is built this will mean hydrogen can be delivered to more and new users. Similarly, with storage, as more hydrogen storage infrastructure is built this will provide greater flexibility to producers and users. Storage will play a vital role in growing electrolytic hydrogen production and ensuring the efficient production of hydrogen by electrolysis, for example, by generating and storing hydrogen using electricity that would otherwise be curtailed.

### Impacts

The combination of these outcomes – mainly coordinated roll out and more hydrogen transport – will create a mature hydrogen economy where producers and users are efficiently connected by hydrogen transport. Storage will provide certainty of supply for end users and could reduce the costs of hydrogen, especially if hydrogen is produced from curtailed electricity. Further, hydrogen storage infrastructure will play a role in electricity balancing (described in the first section) and could contribute to security of supply. Hydrogen transport and storage infrastructure will enable the widespread use of low carbon hydrogen, lowering GHG emissions. Efficient link-up of production and users and the use of hydrogen storage to balance excess renewable generation, especially from our increasing offshore wind capacity, could also lower the costs of decarbonisation. Effective government interventions designed to minimise costs to the consumer and taxpayer will also lower the costs of decarbonisation. Development of the UK supply chain will support jobs and GVA across the UK.

### Objectives

The main strategic objective which underpins energy transformation work, including in the hydrogen space, is the legally binding net zero targets and carbon budget caps which will be met by lowering emissions. Taking the necessary steps so that hydrogen transport and storage infrastructure is available to enable the growth of the hydrogen economy and to provide flexibility and security of supply in the wider energy system will be key to meeting net zero commitments.

The deployment of new transport and storage technologies at scale will both be enabled by and drive UK innovation. Further, and especially in the early phases of hydrogen economy growth, which will likely be concentrated in industrial regions and clusters, hydrogen transport and storage infrastructure deployment will contribute to clean growth and levelling up by creating jobs and investment opportunities.

As outlined in the first section, hydrogen transport and storage could play an important role in supporting whole energy system balancing and help us achieve a fully decarbonised low-cost and flexible power sector. Hydrogen could be generated at times of excess renewable electricity production and either stored as hydrogen to be transported and used for hydrogen demand or converted back to electricity to meet power demand. This role of system balancing is explored more in the strategic planning chapter of the consultation.

# Market barriers

This section summarises the market barriers for hydrogen transport and storage. Although the Theory of Change is similar for hydrogen transport and storage, there are some differences in their market barriers. Transport and storage are therefore considered separately in this section. This allows conclusions to be made about different business model design requirements in the next section.

Market barriers are linked to market failures, where the free market results in outcomes that are not optimal at a societal level. The barriers described below also capture wider constraints currently holding back the development of hydrogen transport and storage infrastructure. These barriers are those which are key blockers to hydrogen deployment in the 2020s. They will evolve and change as the hydrogen economy develops. For more detail on market barriers across the hydrogen supply chain, please refer to the hydrogen strategy analytical annex[61].

The three main categories of market failure that are most relevant to hydrogen transport and storage are: coordination failure, nascent markets with imperfect information and first mover disadvantage. In the future hydrogen transport is also likely to have the additional market failure of monopoly power. Monopoly power could also be a factor in storage, depending on the growth of the hydrogen economy and the role of storage in system balancing. Most of the barriers described below are a result of hydrogen being a nascent market with imperfect information. The first mover disadvantage contributes to the commercial and technological risk barriers while coordination failure results in the supply and demand uncertainty barrier.

## Transport market barriers

**Supply and demand uncertainty**

Uncertainty around hydrogen supply and demand are a barrier for hydrogen transport growth. For example, on the supply side, a challenge for both government and developers of transport projects is that it is hard to predict when there will be sufficient hydrogen production to necessitate larger-scale transport infrastructure. Similarly, with demand, we don’t know when consumers will have the technology to use hydrogen. Further, uncertainty around the locations of where supply and demand will develop make it hard to plan fixed transport infrastructure, e.g., pipelines.

There is a risk of coordination failure if hydrogen infrastructure built to support early deployment is not suitable for wider scale up of hydrogen demand. This could lead to stranded assets or bottlenecks if transport is not aligned with production and demand. The growth of the hydrogen economy is an example of a suboptimal equilibrium where market growth requires enough participants to enter at the same time (coordination) but where the risks (e.g., technological and commercial) deter new entrants.

Hydrogen transport infrastructure may need to be extensive to meet a high hydrogen demand scenario in 2050. These larger-scale projects, the biggest of which could involve repurposing most of the existing gas network, would take decades. Long lead times exacerbate this barrier as some certainty on other barriers described (e.g. commercial frameworks, regulation, policy intent) are necessary years ahead of when the infrastructure may be required. Futureproofing the network will be more difficult because of supply and demand uncertainty. If the network isn't future proofed, there could be higher costs in the long run if smaller pipelines need to be replaced with larger pipelines as demand grows.

**Limited consumer base to cover costs**

Natural gas is the main counterfactual to hydrogen and natural gas costs are passed onto a very large consumer base. Currently there are no hydrogen consumers to pass hydrogen transport costs onto and there will be very few hydrogen consumers while the hydrogen economy is growing.

Having many consumers paying for the national gas network keeps costs per consumer low for gas transport. Because the counterfactual spreads costs over a very wide base, this means without intervention or support the cost of hydrogen transport would have costs much higher than e.g., natural gas for a long time.

**High cost**

There is currently very limited hydrogen transport infrastructure as hydrogen use is small-scale and hydrogen is often produced and used in the same location. Transport infrastructure therefore needs to be built or repurposed which will incur high up-front costs.

Smaller-scale transport infrastructure could be suitable for individual production sites providing hydrogen for a limited number of users. In this case, the up-front costs will be lower, but hydrogen producers will be competing against the main counterfactual, natural gas. Natural gas transport has the benefits of economies of scale and mature supply chains and an established national network with relatively low operating costs. Hydrogen producers cannot compete with counterfactual fuels before passing additional transport costs onto consumers. Passing any additional transport costs (even for small-scale infrastructure) would therefore further impede hydrogen's competitiveness.

**Policy and regulatory uncertainty**

The lack of a clear and consistent long-term policy and regulatory framework for hydrogen transport deters investors as it adds risk to the investment process. Investors may not have the information available to fully consider the implications of the 2050 net zero target when making investment decisions and may also perceive a high risk of stranded assets if subsequent policy and regulatory decisions markedly change the operating environment for hydrogen transport. For example, the decision on the role of hydrogen in heat – due in 2026 - will impact how much of the existing gas network would be repurposed for hydrogen.

### Technological risks

Outside of current industrial uses, hydrogen transport has not been fully tested at scale, and it is not clear what purity standards are required for hydrogen distributed in pipelines to be used by different end users. This also applies to blending, where the safety profile and commercial feasibility are still being established. Further, there are new and innovative solutions for hydrogen transport which are untried and tested. The considerable technological uncertainties and risks will be more acute for the earliest projects.

### Commercial risks

Commercial frameworks for hydrogen transport are unknown, with this consultation being the first public engagement on business models for hydrogen transport. There will likely be different frameworks operating over time e.g., initial support for early smaller-scale transport via existing policies (production Hydrogen Business Model, Net Zero Hydrogen Fund and the Renewable Transport Fuel Obligation) followed by a specific transport business model.

Further, in a new and nascent market there is the ‘first mover disadvantage’. Project developers for the first hydrogen transport projects will bear significant learning costs and risks but may not capture the full benefits of the investment, as market competitors use their knowledge. Some of the market barriers described here (e.g., supply and demand uncertainty) increase the commercial risk.

### Competitive advantage

Repurposed gas network infrastructure could be the best solution for hydrogen transport once converted. Existing gas network providers are progressing development work on this, described in the evidence section of this annex. The above favours existing gas network providers and is a barrier for new entrants to the market, impeding competitiveness. However, repurposing existing assets may be the cheapest and quickest way to build hydrogen transport infrastructure, benefitting consumers and government.

### Natural monopoly

If a hydrogen network is built (or repurposed), this could be a natural monopoly where producers and consumers are only able to use one network, like the gas network now. Owners and operators could block potential users or reduce access for users of the network, which is likely if a producer or consumer owns and operates the network (a vertical risk). Further, owners and operators could charge excessive prices for using the networks if there are no or few alternatives (a horizontal risk). Natural monopolies therefore require different policy design and regulation to counter the lack of competition and protect consumers from market failures.

## Storage market barriers

The following section can be read in isolation as the market barriers for storage have been laid out in full. This means where there is an overlap between the barriers for transport and storage, there is some duplication with the descriptions below and those in the transport barrier section above.

**Demand uncertainty**

Uncertainty around potential demand for hydrogen storage is a barrier for storage growth. It is hard to predict when and how much storage will be needed by users. Further, uncertainty around the locations of where supply and demand will develop make it hard to plan fixed hydrogen storage infrastructure, e.g., salt cavern storage.

The volume of storage required depends on the patterns and types of hydrogen production and demand, not just total production and demand. Hydrogen use in heat for example would have significant peaks and troughs both daily and seasonally, meaning storage is needed even if hydrogen production is constant. Other users, e.g., in industry, might have flatter demand profiles. Different storage technologies will be suitable for short-term and long-term supply and demand balancing. For example, above ground storage (in e.g., specialised tanks) could mitigate against short-term demand shortages whereas salt caverns would be more suitable for longer-term balancing as the rate of change in gas pressure must be limited[62]. Production technologies differ in their abilities to operate flexibly, with CCUS enabled Steam Methane Reforming (SMR) having by far the lowest level of flexibility[62,63]. Having storage infrastructure available for when there are insufficient off-takers, due to e.g., a temporary outage, could provide certainty to hydrogen producers that they can operate safely and efficiently with fewer risks. Because storage is tied to the types of production and demand, this increases the uncertainty around hydrogen storage requirements.

Hydrogen storage could play an enabling role in the wider net zero economy, not just hydrogen economy growth. As laid out in the first section, hydrogen storage could facilitate low carbon electricity production by storing renewable electricity generated when electricity demand is low. The dependencies on other net zero technologies increases the uncertainty around hydrogen storage requirements. There is a risk of coordination failure if hydrogen infrastructure built to support early deployment is not suitable for wider roll out of hydrogen demand. This could lead to stranded assets or bottlenecks if storage is not aligned with production and demand needs. The growth of the hydrogen economy is an example of a suboptimal equilibrium where market growth requires enough participants to enter at the same time (coordination) but where the risks deter new entrants.

[62] https://www.gov.uk/government/publications/hydrogen-supply-chain-evidence-base (Viewed on 7 July 2022)
[63] SMR is the most restrictive in terms of ramp-up and ramp-down due to the high temperature requirement. For all CCUS enabled technologies, efficiency is reduced if output varies, with SMR risking the most serious damage.

Large amounts of hydrogen storage may be needed to meet the needs of a high hydrogen demand scenario in 2050. These larger-scale storage projects have long lead-in times due to planning procedures, environmental impact assessments and geological engineering work. Long lead times exacerbate the supply and demand uncertainty barrier, meaning some certainty on other barriers described (commercial frameworks, regulation, policy intent) are necessary years ahead of when the infrastructure may be required.

### High cost

In the UK, there is one operational hydrogen storage site in Teesside. Some storage infrastructure could be repurposed from existing gas storage, but new storage sites will likely be needed too to meet the demand for storage. Evidence suggests that on-going storage costs could be relatively low but the up-front costs, for both new and repurposed sites, will be very high[64]. Hydrogen producers cannot compete with counterfactual fuels before passing additional storage costs onto consumers. Passing high storage costs onto hydrogen consumers would further impede hydrogen's competitiveness.

### Policy and regulatory uncertainty

The lack of a clear and consistent long-term policy and regulatory framework for hydrogen storage deters investors as it adds risk to the investment process. Investors may not have the information available to fully consider the implications of the 2050 net zero target when making investment decisions and may also perceive a high risk of stranded assets if subsequent policy and regulatory decisions markedly change the operating environment for hydrogen storage. For example, the decision on the use of hydrogen in heating will impact the volumes of storage required to manage daily and seasonal fluctuations in demand.

### Commercial risks

Commercial frameworks for hydrogen storage are highly uncertain, with this consultation being the first public engagement on hydrogen storage business models. There will likely be different frameworks operating over time e.g., initial support for early small-scale storage via existing policies (production Hydrogen Business Model, Net Zero Hydrogen Fund) followed by a specific storage business model.

Further, in a new and nascent market there is the 'first mover disadvantage'. Project developers for the first hydrogen storage projects will bear significant learning costs and risks but may not capture the full benefits of the investment, as market competitors use their knowledge. Some of the market barriers described here (e.g., supply and demand uncertainty) increase the commercial risk.

[64] For example, Figure 21 in the report Supply chains to support a UK hydrogen economy estimates the cost of developing salt caverns to provide the storage capacity requirements estimated for 2030 in National Grid's FES scenarios is between £1.2bn and £2.3bn: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1092371/supply-chains-to-support-uk-hydrogen-economy-wood-template.pdf (Viewed on 22 August 2022).

**Competitive advantage**

Repurposed gas storage infrastructure could be the best solution for some hydrogen storage once converted. Existing gas storage providers are progressing work on this. The above could favour existing gas storage providers and be a barrier for new entrants to the market, impeding competitiveness. In some instances, repurposing could however mean that existing providers need to buy themselves out of existing storage contracts, therefore increasing the costs. Repurposing may be the quickest way to build some of the necessary hydrogen storage infrastructure, and in some cases the cheapest, so could be beneficial for consumers and the government.

# Comparison

To provide further context, a comparison between the market barriers for hydrogen transport and storage and market barriers in other areas of energy infrastructure deployment follows. Any steps taken to overcome these market barriers are also included below.

**Supply and demand uncertainty**

Production, transport, storage, and demand are all linked and uncertainties in both transport and storage growth also create more uncertainty for hydrogen production and hydrogen demand. The extent to which hydrogen will play a role in system balancing exacerbates the uncertainty of hydrogen storage growth. Decisions on cluster sequencing, allocation of production Hydrogen Business Model contracts and increasing evidence on known projects in the pipeline will reduce this barrier. However, while the hydrogen economy is growing there will still be significant uncertainties for transport and storage.

**High cost**

The main counterfactual, natural gas, has larger-scale established production, transport, and storage facilities. Hydrogen requires new infrastructure to be built which will cost more in the short term than running costs for established infrastructure. However, some hydrogen transport and storage infrastructure will probably be repurposed gas assets. For hydrogen transport, there is the potential that most larger scale infrastructure could be repurposed. On the other hand, we predict that new hydrogen storage sites will be needed as there may not be sufficient gas storage capacity (currently 16TWh in the UK[13]) that can be converted. This is especially the case in the initial growth period of hydrogen as gas storage may still be needed to maintain security and resilience in the gas system. Although transport and storage infrastructure can be repurposed, almost all hydrogen production facilities will need to be built from scratch, increasing the production costs. For hydrogen production, the key risk associated with the barrier of high cost is an inability to compete with the counterfactual, natural gas. Price support delivered through the production Hydrogen Business Model is designed to overcome this market price risk[14]. With longer-term transport and storage infrastructure, the key risk associated with cost is high upfront capital costs with a limited user base to cover these. This risk links to and is exacerbated by supply and demand uncertainty.

**Policy and regulatory uncertainty**

There are more policy signals for hydrogen production compared to hydrogen transport and storage. BEIS have committed to design a transport business model and a storage business model by 2025[6] whereas the NZHF and HBM designed to support hydrogen production are open for applications. Hydrogen could be transported via repurposed gas networks which have their own, established regulatory framework. The regulatory framework for hydrogen transport could mirror or evolve from this existing regulation, meaning there is more certainty on possible commercial arrangements for hydrogen transport.

**Technological risks**

Comparing the growth of the hydrogen economy to e.g., the recent growth of renewable electricity, there were fewer technological risks for transportation as renewable electricity could be distributed by the established electricity network without repurposing. To overcome the technological risks for hydrogen, safety testing is underway for transport and storage. For example, BEIS is supporting the design of hydrogen village trials[65].

**Commercial risks**

A commercial framework (the production Hydrogen Business Model) has been launched to support hydrogen production while commercial frameworks for hydrogen transport and storage will be designed by 2025. Although necessary to support initial projects, if funding for transport and storage is delivered through more than one framework or policy, this will add more complexity to transport and storage support.

We predict the following two market barriers will be key for hydrogen transport and storage and play less of a role in other parts of the hydrogen supply chain.

**Competitive advantage**

This barrier is more extreme for hydrogen transport and storage as gas assets could be repurposed for hydrogen. This is especially true for hydrogen transport.

**Natural monopoly**

Larger-scale hydrogen networks are more likely to be a natural monopoly in the longer term than hydrogen production. Conversely, while hydrogen production is in its infancy, neither a producer or hydrogen transport would exert a monopoly pull as one producer or pipeline will not be serving many users. Hydrogen networks will be a monopoly if or when we move to a phase where there are multiple hydrogen producers and users using one hydrogen network.

[65] https://www.ofgem.gov.uk/publications/consultation-our-minded-decision-fund-detailed-design-studies-hydrogen-village-trial (Viewed on 20 June 2022)

# Business Model design

In the broadest sense, a business model is the plan for how a business makes money and delivers value to customers at an appropriate cost. Here, and across government, we use the term business model to describe a commercial framework designed by government (in collaboration with industry) that is necessary to stimulate growth in a given sector while delivering value for money for the government. Business models designed by government will allocate risk appropriately between government and the private party. If the government needs to design a business model, we can assume the government needs to take on some risk to overcome market barriers. To overcome these risks, government price support may be necessary alongside other interventions and policies.

Based on the market barriers described above, input from potential investors and similarities with other infrastructure deployment needed for net zero, the government has committed to designing Business Models for transport and storage by 2025. To achieve the vision laid out in the Theory of Change and the Hydrogen Strategy[58], a range of government interventions will be needed, some of which will be delivered through a business model. Without appropriate business models, we expect there would be no at-scale deployment of hydrogen transport and storage in the UK in the next decade.

Although there are similarities between transport and storage, they will fulfil different roles in the hydrogen economy and energy system and have different market barriers, described in the previous section. We therefore suggest separate business models will be needed for hydrogen transport and hydrogen storage.

In the first half of this section, a framework of questions to consider when designing a business model is described. Using this framework alongside the Theory of Change and Market Barriers allows us to make initial conclusions about the design of hydrogen transport business models and hydrogen storage business models (described in the Design options section). It also highlights areas where we need more information to design effective business models so has informed some questions included in this consultation. Further, by publishing this we can test the suitability of this framework and our initial conclusions on business model design.

A business model should factor in the needs of transport and storage owners (and their investors), transport and storage users and the government. The requirements of these stakeholders will sometimes be in conflict and a good business model will have reasonable trade-offs to satisfy all parties. Owners and investors need the business model to overcome key market barriers and provide an appropriate return for the risk of the investment. Both producers and users of hydrogen will need certainty over the availability of transport and storage infrastructure to participate in the growing hydrogen economy. The government has a responsibility to ensure the business model provides value for money for consumers and taxpayers while enabling efficient roll-out of infrastructure to meet legally binding net zero targets and carbon budgets.

The following design principles are based on analysis for the production Hydrogen Business Model[38]. These criteria are common across business model design and can be applied to transport and storage.

**Key design principles**

**Investable:** the business model should provide sufficient predictability over revenue and return to investors and mitigate risks which investors are not best placed to bear.

**Promotes market development:** the business model should incentivise transport and storage providers to optimise the use of their infrastructure.

**Compatible:** the business model should be compatible with other policies across the value chain and should not result in double subsidisation.

**Avoids unnecessary complexity:** the business model should avoid unnecessary complexity for government to design, implement, and administrate over time, and for transport and storage providers to understand and comply with over time.

**Reduces support over time:** the business model should allow for support to reduce over time by being responsive to market conditions, the changing risks as the hydrogen economy grows and by incentivising learning and innovation to drive cost reductions over time.

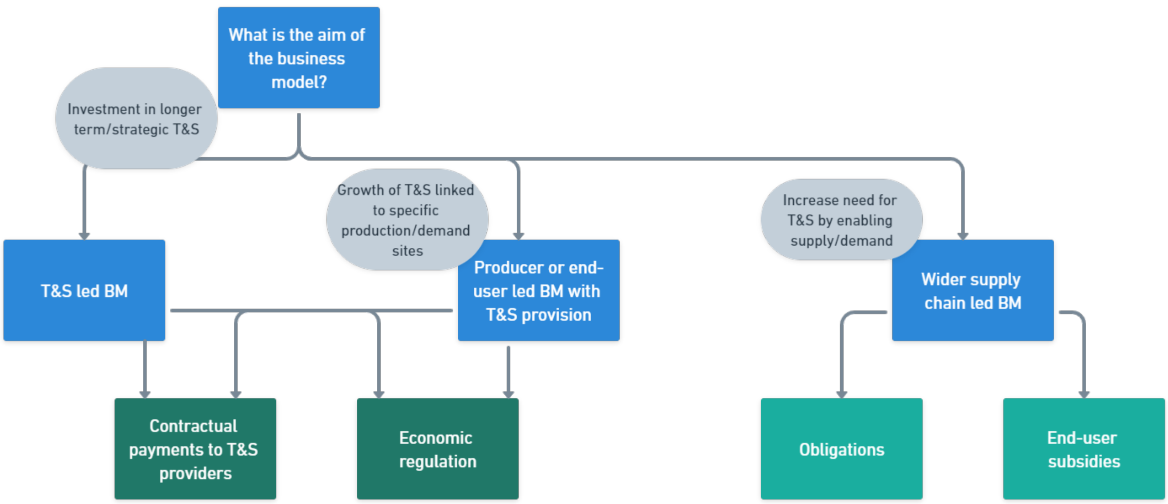
**Suitable for future pipeline:** the business model should be fit for purpose for first of a kind (FOAK) projects as well as next of a kind (NOAK) projects.

# Design framework

The following 12 questions aim to tease out the different aspects of business model design. This framework does not provide a comprehensive list of considerations or options for business model design. There is a multitude of additions and tweaks that can be incorporated into a business model and this framework is intended to facilitate the design process. The main driver of business model design is the appropriate allocation of risk between the government and transport and storage providers. Changing risk profiles will need to be incorporated into the evolution of business model design.

1. **What is the aim of the business model?**

**Figure 6: Flow chart to decide suitable category of business model**




This question identifies where in the hydrogen economy the business model needs to be targeted. If the aim of the business model is investment in longer-term and strategic transport and storage growth, then a business model needs to be targeted at transport and storage specifically. However, if the aim is to enable growth of smaller-scale transport and storage infrastructure linked to specific production or demand sites, then the business model could be producer or end-use led with provisions to enable necessary transport and storage. Alternatively, if the aim is to increase the need for transport and storage by generating more supply and demand in the hydrogen economy then a business model could be directed elsewhere in the value chain, to producers or users.

## 2. What type of business model is suitable?

Business models can be categorised into four broad groups, summarised below[66].

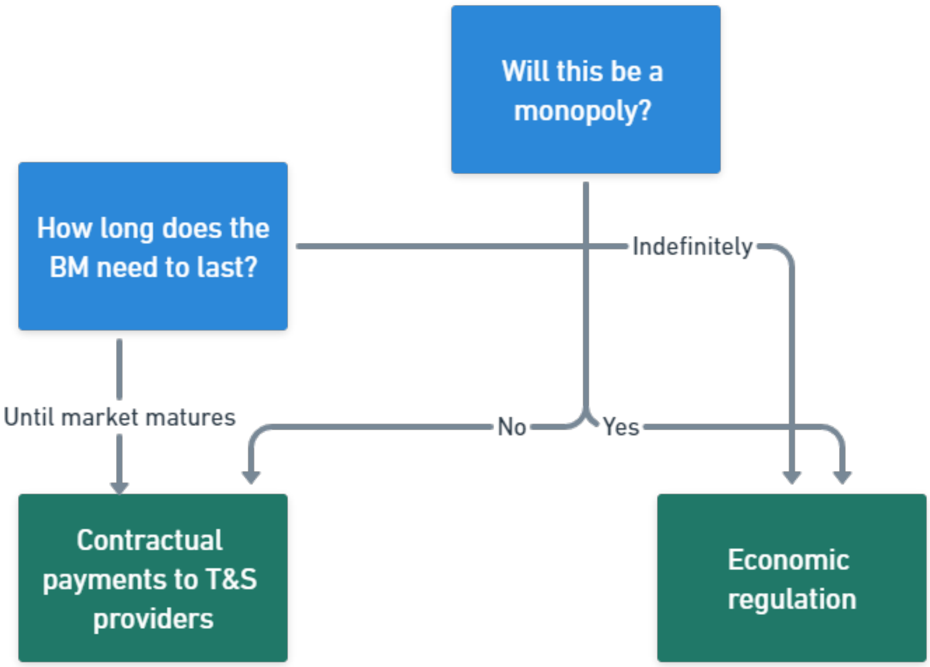
| | |
|---|---|
| Contractual payments | A bilateral contract is agreed between a transport or storage project and a counterparty. Detailed terms and conditions, signed prior to the construction of an asset provide investors with certainty. Examples include Contracts for Differences (CfDs) used in renewable electricity. |
| Economic regulation (regulated returns) | Economic regulation would provide a guaranteed return on the cost of a transport or storage project, giving certainty to investors. Examples include a Regulated Asset Base (RAB) used for natural gas networks. |
| Obligations | An obligation is imposed on parties outside the transport or storage sector (e.g., end users or producers) to e.g., use a certain quantity of stored hydrogen. |
| End user subsidies | For example, an ongoing technology-neutral subsidy is provided to end users for carbon abatement. |

Obligations and end user subsidies could be the basis of business models designed to e.g., favour switching to hydrogen. This would increase the demand for hydrogen and in turn increase the need for hydrogen transport and storage infrastructure. However, business models elsewhere in the value chain, e.g., to drive hydrogen demand, would not guarantee use (and therefore revenue) for the transport and storage infrastructure. Regulated returns or contractual payments are suitable for transport and storage led business models and producer/end-user led business models with a provision for some transport and storage. Regulated returns or contractual payments are more effective at giving confidence to investors, particularly for larger-scale assets requiring significant upfront investment. Policy-based approaches (e.g., obligations) in the wider hydrogen economy bring more uncertainty, as they are not designed around the specific market barriers for transport and storage and can be changed by governments.

[66] https://www.frontier-economics.com/media/4157/business-models-for-low-carbon-hydrogen-production.pdf

To decide whether contractual payments or regulated returns would be most suitable, the two questions below need to be considered. Note that a hybrid of these two options is also possible, e.g., a Regulated Asset Base with a provision for contractual payments as part of this. Additionally, a direct transport and storage business model (delivered by a RAB or contractual payments) with a policy-based approach (e.g., obligations or end-user subsidies) layered on top could be instigated. The direct business model would act to provide certainty to investors while the additional policy-based approach would be designed to drive market development and efficient use of the infrastructure.

**Figure 7: Flow chart to decide type of business model**




If the system will have monopolistic qualities, then economic regulation with regulated returns would be preferable to contractual payments. Regulated returns should allow for more additional measures in the business model design that will drive efficiency and fair prices, in the absence of competition. If the business model is only needed to kickstart the market, then contractual payments would be most suitable. Alternatively, if the business model and associated commercial framework needs to last indefinitely then a regulated return business model is preferable. For example, with a monopoly system (whether a true monopoly or a system with monopolistic qualities) the provision of indefinite regulated returns can protect consumers in the long run as well as driving growth in the short-term.

### 3. What are the key market barriers the business model is trying to overcome?

We predict that in the near-term hydrogen transport and storage will not be built at-scale without government intervention. The purpose of the business model is to enable the growth of the market by overcoming or reducing market barriers. Transport and storage market barriers are described in detail in the previous section.

### 4. Who are the likely investors and operators?

Investors are key to realising growth of the hydrogen economy and business model design cannot be considered in isolation. Understanding potential investors and operators allows you to identify their different requirements from a business model. For example, incumbent gas storage providers planning to expand into hydrogen storage will for example, have different needs than a smaller company developing a new above-ground storage technology.

Asset finance uses a company's balance sheet assets for investment, and this investment can either come from internal company balance sheets, debt finance (borrowing of money), or from equity finance (selling a portion of the company). Additionally, investments can come from venture capital or private equity funds who in turn typically raise money from institutional investors such as pension funds.

## 5. What type of costs need support?

Projects have different types of costs at different stages:

- **DEVEX** costs are development costs mainly incurred early in the project
- **CAPEX** costs are the capital costs needed for e.g., construction
- **OPEX** costs are ongoing operating expenses

The price support needed will be based mainly on the key market barriers the business model is designed to overcome (question 3), the likely operators and investors (question 4) and other policies in this space. For example, if DEVEX support is provided in a policy separate to the main business model, that may reduce the DEVEX support needed in the business model.

| | |
|---|---|
| DEVEX/CAPEX | Stand-alone DEVEX and CAPEX support could help overcome technological and commercial risks. Both DEVEX and CAPEX will help to address upfront cost and risk hurdles, with DEVEX support stimulating new proposals and technologies and CAPEX support potentially allowing developers to take Final Investment Decisions (FID) and progress their projects.<br><br>DEVEX and CAPEX support could also generate learnings to drive down the cost of future projects. Additionally, incorporating DEVEX and CAPEX support into a revenue support mechanism could reduce the lifetime costs of the projects and potentially the costs to the consumer and taxpayer. |
| Revenue support | Revenue support can be designed in many ways, but all would be characterised by enabling transport and storage providers to earn enough revenue to recover costs (DEVEX, CAPEX and OPEX) and earn a sufficient return on investment.<br><br>On its own, capital support (CAPEX) is unlikely to overcome the key market barrier of supply and demand uncertainty. Therefore, a revenue support model with a minimum economic return to cover fixed and/or variable costs would be necessary. |

Throughout the lifetime of a project, there are different phases which have unique costs and risks. In the early development stages, resolving technological, regulatory and market uncertainties is critical to assess the feasibility of a project. Once the feasibility has been established, securing financing and predictability over future revenue stability is crucial for the engineering, procurement, and construction phase to begin. During the operating phase, the risks to revenue stability are the main consideration. Business model design needs to consider the different needs throughout a project and that different types of support might be needed across the span of a project. This would include provisions to taper off support in the operation phase when it is no longer necessary.

## 6. How should price support be delivered?

With this question, the overriding principle is that government business models should minimise the cost to the consumer and taxpayer. This question is based on the market barriers (question 3), the types of costs (question 5) and any other interventions available. Other policies in this space need to be considered to avoid subsidy stacking.

DEVEX and CAPEX support could be provided by an upfront grant or loan to co-fund or fully cover costs. DEVEX and CAPEX costs can also be incorporated into and therefore supported via the revenue support options below. Revenue support could be provided through mechanisms to overcome market-price risk, volume risk, or a combination. Market-price risk is associated with the market barrier of high cost where end users are unable or unwilling to pay the full cost of the good or service but would fully utilise it if available at a price which they can afford. Volume risk is associated with the market barrier of supply and demand uncertainty where, for example, providers cannot be certain there will be sufficient hydrogen production and use to necessitate transport and storage infrastructure use and cover costs. These risks will decrease as the hydrogen economy develops and price support will evolve to reflect the changing risks. A business model with price support may be time-limited or regulated returns, for example, could be an enduring feature of a commercial framework.

Some mechanisms to deliver revenue support to counter market-price risk and volume risk are described below. As noted at the start of this section, these are potential options and should not be viewed as a comprehensive list of all considerations.

*Market-price risk options*

| | |
|---|---|
| Fixed price | A fixed price is paid per unit, irrespective of the value achieved. Example included Feed-in Tariffs (FiTs) for small-scale renewable electricity generation. |
| Fixed premium | A fixed premium is paid on top of the value achieved, this can be absolute or a percentage uplift. |
| Variable premium | A premium is paid, which is calculated as the difference between a 'strike price' and a 'reference price'. There is also the potential for the government counterparty to be paid the difference if the reference price rises above the strike price. |

Although relatively simple, with fixed price and fixed premium support there is a risk of over-subsidisation if market values rise, or costs reduce, while the subsidy remains fixed. With variable premiums there is less risk of over-subsidisation (as the subsidy adjusts through the reference price as the market evolves). However, deciding the strike and reference price can make this option more complicated.

*Volume risk options*

| | |
|---|---|
| Availability-based payments | A transport or storage provider is paid for providing a given amount of transport/storage capacity allowing them to make a minimum economic return irrespective of whether the infrastructure is being used and costs recouped. Availability-based payments can provide support for resources and infrastructure that might otherwise be unavailable in the market due to an intermittent need for them.<br><br>This could be designed so that storage operators are only paid by a government business model for providing the service when they are unable to recoup payment from users.<br><br>These are used in e.g., the GB capacity market where capacity providers are paid regardless of whether the assets are generating or not with the aim of ensuring reliable sources of electricity capacity are available when needed. |
| Government backstop or front stop | A financial backstop could be provided if there are no or insufficient users to pay for the transport and storage infrastructure – acting as a minimum revenue guarantee. This could also be designed as a 'front stop', where the government is the offtaker of last resort and only provides payments if an agreed volume of capacity remains unsold.<br><br>A government backstop or front stop can operate at different levels e.g., a backstop where support is only in place prior to the first user, through to partial or 'full' cover. Depending on the design, 'full' cover could be broadly equivalent to availability-based payments. |
| Regulated returns | Returns could be fully regulated, and a revenue guarantee provided to cover all costs and provide a sufficient return on investment. Alternatively, returns could be delivered by a cap and floor model. Here, the maximum revenue is capped, and the floor provides a minimum revenue guarantee. A cap and floor model can allow for additional profits and incentivise efficient operation. If the floor is lower than in a fully regulated return model, the costs to consumers and government could be lower. However, with significant supply and demand uncertainty, a floor may not provide sufficient revenue guarantee.<br><br>The allowed revenue can be calculated in different ways to shift the recoup of revenue to later when there should be more users. This can be done by e.g., backloading depreciation. |
| Sliding scale | A sliding scale manages volume risk through the price support received. A variable strike price ensures that higher price support is paid for initial units sold, allowing costs to be recovered when there is a relatively low number of asset users. Price support then tapers off as the number of units sold increases. |

The four volume-risk price support options listed above are high-level examples of support options. There are additional possibilities which could fall between the listed examples above and as discussed at the start of this section, there are many additional design features that can be incorporated, some of which are discussed below.

In between availability-based payments and a government backstop, the government could directly contract for capacity but allow or require the infrastructure provider to remarket that capacity. This would de-risk the investment (by overcoming initial volume risk) and in time allow the government to phase out support.

Regulated returns and a sliding scale mechanism (depending on the design) can also mitigate price risks. With the above options, support could be split into fixed and variable costs. For example, fixed costs could be paid even if there was no demand for the infrastructure and variable costs would only be paid if there was hydrogen to transport and store. Splitting the support into fixed and variable could reduce the cost to the government or consumer and incentivise transport and storage providers to secure connections. Price support in all these options can also be designed so it is backloaded, e.g., one example in the table above is to backload depreciation in a regulated return model. Whether backloading provides value for money would need to be assessed, as backloading can cost more money. This is because of the concept of time value of money (TVM), where a sum of money is worth more now than the same sum in the future, due to its earning potential in the interim.

The design of revenue support to overcome volume risk needs to balance two factors. Firstly, sufficient revenue needs to be guaranteed to provide certainty to investors. However (and secondly), by not guaranteeing all the revenue to cover costs and guarantee a return on investment (e.g., in a cap and floor regulated return model or not covering variable costs in availability-based payments), this could incentivise optimisation. Here, transport and storage providers would be encouraged to secure their own users, and this could reduce the risks and costs taken by government. This trade-off will depend on the how severe the volume risk is when projects are needing to make final investment decisions (FIDs).

7. **What incentives can be incorporated into the design and delivery of the business model to ensure efficiency and value for money for consumers?**

Rather than just ensuring infrastructure is built, the business model should incentivise the use of transport and storage. The effective use of transport and storage is key for the Theory of Change to be realised. This is especially important if the system is a monopoly and competition won't drive down prices and ensure efficiency. Incentivising optimisation will also be key in a business model where returns are fully regulated. Some examples which can be incorporated into price support design to increase efficiency include e.g., allowed revenues for each unit of transport and storage availability above the target level, penalties when transport and storage isn't available as scheduled, or a connections incentive.

This links to the first question covering the high-level categories of business model. One option is a hybrid of a direct business model with a policy-based approach. This policy-based approach could be delivered via the direct business model or as a separate policy (or policies) alongside the business model. The policy would be designed to drive market development and the use of the infrastructure, ensuring efficiency and value for money.

8. **What steps outside of the price support design will be in place to mitigate the volume risk and reduce revenue support?**

Revenue support will mitigate for volume risk, but the government needs to ensure it is not taking on too much of the risk and subsidising transport and storage that is not needed. This is a trade-off and in an emerging market some risk will need to be taken to kickstart growth. In addition to the design of the price support delivery (e.g., split payments for fixed and variable costs and a cap and floor model, described in question 6), this risk can be mitigated for in the design and delivery of the business model. For example, in any assessment phase, checks can be taken to make sure the provider has identified known producers and users. Projects linked to clusters could also be prioritised in the first instance.

9. **How are costs recovered?**

For this question, the cost recovery mechanism in the steady state and the growth period needs to be considered. The growth period is where the market barriers are pervasive.

a. How are costs recovered in a steady state?

In the long-term, we predict hydrogen transport and storage will be paid for by hydrogen users.

b. How are costs recovered in the growth period?

While there are no or few hydrogen consumers and costs of building hydrogen transport and storage infrastructure are high, a user pays model will not be feasible. Costs (including any price support needed to overcome the market barriers) will therefore need to come from other sources, for example:

- Taxation
- Levy on energy bills
- Cost mutualisation with natural gas consumers through network charges

There are important considerations when designing how costs could be supported in the growth period, some of which are described here. Affordability and fairness for energy users and taxpayers needs to be considered as well as the impact on fuel poor households and energy intensive industries. Future users of hydrogen should be factored in when assessing the principle of fairness. E.g., if the transport sector becomes a big user of hydrogen, it may not be fair for costs to be solely mutualised with natural gas consumers through network charges.
The decision needs to protect public finances and be consistent with fiscal sustainability whilst also allowing a business model to be delivered as quickly as

possible. Lastly, the approach established needs to be robust to future changes in the energy system and the scale of hydrogen growth.

We envisage cost recovery from parties other than hydrogen users to taper as transport and storage costs reduce and the hydrogen user base increases. The business model design should factor in how to reduce subsidies as market barriers decline.

### 10. Does the government have a role in other risk management?

A business model will have price support mechanisms in place to counter key market barriers and overcome the risk to investment. The government could also have a role in other risk management, covering low probability but high-risk scenarios not factored in elsewhere. This could include protection for stranded assets and/or insurance.

### 11. How will the business model be delivered?

Contractual payments could be delivered by competitive auction or bilateral negotiations. These two approaches could also be mixed, e.g., a competitive process to decide which projects enter bilateral negotiations with government. A competitive framework could also be used to decide which projects are supported by regulated returns. To deliver economic regulation a new Regulated Asset Base (RAB) could be instigated, or e.g., the existing natural gas RAB amended. When considering the revenue support options to overcome volume risk (question 6), the option of regulated returns would be delivered by economic regulation. Availability-based payments, a government backstop or a sliding scale business model could be delivered by contractual payments or by economic regulation.

### 12. Which organisations will be involved in delivering the business model?

The organisations needed to deliver a business model will depend on the design of the business model, mainly whether the business model will be a contractual arrangement or regulated returns (question 2) and how the business model will be delivered (question 11). A counterparty would need to be appointed to manage contracts in a contractual model and a delivery body to run an auction would be needed to run competitive auctions. For example, the Low Carbon Contracts Company[67] manages Contracts for Difference (CfD) with low carbon electricity generators. Ofgem regulates monopoly companies who run the gas and electricity networks and sets price controls for these Regulated Asset Bases (RABs). Ofgem would therefore likely have a role in regulating future hydrogen networks which could be ran by monopoly companies, some of which may be the same companies as those currently running gas networks.

[67] https://www.lowcarboncontracts.uk/ (Viewed on 7 July 2022)

# Design options

In this section, initial answers to questions in the design framework are proposed for transport and storage in turn. Not all questions are considered here, only those where we can make a reasonable assumption based on existing evidence.

**Transport**

| | |
|---|---|
| 1. What is the aim of the business model? | Policies and business models focused on the wider hydrogen economy, e.g., end-user led subsidies and obligations should increase the demand for hydrogen transport but will not necessarily lead to investment in strategic and long-term transport infrastructure that would support multiple users. Additionally, business models in the wider supply chain would not provide sufficient certainty for transport providers.<br><br>Production or end-user led business models with support provided for transport will enable site-specific transport to be built. However, relying solely on producer/end-user led business models may result in lots of user-specific infrastructure when a connecting network of transport infrastructure could have serviced needs more efficiently.<br><br>A **transport-led business model** is preferable to production or end-user led business models alone as this will allow strategic transport to be built which can service multiple producers and users more efficiently. Alongside this, **initial support for small-scale transport via production led business models** is necessary for growth of the hydrogen economy.<br><br>**Policies** with the aim of driving market development and use of transport infrastructure could be incorporated into a transport-led business model or delivered alongside a business model. The business model would be designed to overcome the key risks to enable investment while additional policies could drive efficiency and value for money by encouraging use of the infrastructure. |
| 2. What type of business model is suitable? | A key driver of whether the system will have monopolistic qualities or not is system complexity. In the early stages of hydrogen economy growth, hydrogen transport will likely be integrated with specific production projects and will not have a monopoly pull. However, in later stages of hydrogen economy growth, multiple producers and multiple users could rely on one transport network and the transport system will likely have monopolistic qualities. |

| | |
|---|---|
| | Assuming transport will have monopolistic qualities, then a business model and commercial framework delivered indefinitely by **regulated returns** would be preferable. In this instance, regulated returns could protect users in the absence of competition in the long-run in addition to enabling growth and investment in the short-term. |
| 3. What are the key market barriers the business model is trying to overcome? | With small-scale transport linked to specific production sites, the main market barrier is the high price to transport hydrogen that has been produced to an end user using any necessary infrastructure. Hydrogen will mainly be competing against natural gas so needs to be cost competitive with gas at the point of use. This is a market price risk and policies would need to be designed to make the cost of production plus transport competitive. Where transport is linked to a specific production and demand site, supply and demand uncertainty is less of a barrier.<br><br>For transport infrastructure to support multiple producers and end-users, **supply and demand uncertainty** is the main market barrier. In the future, the potential for hydrogen transport to be a **monopoly** could also be a key market barrier. Additionally, the **up-front costs** for larger transport infrastructure will be very high and these costs cannot be passed onto hydrogen users while there are no or **few hydrogen consumers**. These market barriers are described in detail in the above section.<br><br>For new and unknown transport technologies, technological uncertainty will be the main market barrier. Market barriers will change as the hydrogen economy grows and the design of the business models will need to be adaptable. |
| 4. Who are the likely investors and operators? | Incumbent gas network operators could be future operators of hydrogen transport and these companies have plans to repurpose current gas infrastructure for hydrogen and build new pipelines. Proposed projects in the public domain are summarised in the pipeline evidence.<br><br>Incumbent operators and potential new operators will need investors and more evidence on likely investors, particularly for innovative transport technologies is needed. This is something we are hoping to gather evidence on from this consultation. |
| 5. What type of costs need price support? | If there are potential investors in innovative transport technologies, these may benefit from upfront DEVEX and CAPEX support to overcome the barrier of technological uncertainty. |

| | |
|---|---|
| | Providing DEVEX and CAPEX support could also reduce the overall costs of the project and therefore decrease price support needed and lower costs to the consumer and taxpayer.<br><br>Some price support for small-scale transport will be provided by the initial contracts awarded through the production Hydrogen Business Model (if it is deemed to be necessary, affordable and value for money), so the focus in this consultation is on enduring price support needed for larger transport infrastructure. As the key barrier for larger transport infrastructure is supply and demand uncertainty, **revenue support will likely be necessary.** Capital support alone is unlikely to incentivise investment in transport infrastructure as this will not alleviate the supply and demand barrier. Revenue support could also minimise the risk of stranded assets. |
| 6. How should price support be delivered? | Focusing on larger-scale transport, revenue support will need to be provided to overcome volume risk and supply and demand uncertainty. Because of our conclusions from question 2 – that a regulated returns model would be preferable for hydrogen transport because transport will likely have monopolistic qualities, it may be favourable to deliver price support for volume risk via a **regulated asset base**. This could be fully regulated returns or e.g., a cap and floor model with a minimum revenue guarantee as well as a maximum revenue cap.<br><br>As the policy progresses, a key challenge will be designing price support for a system where the user base is initially a small number of large users, but which could transition to a system with many users. |
| 11. How will the business model be delivered? | If price support for a transport business model is delivered by regulated returns, economic regulation will be needed and would likely be delivered through a **regulated asset base**. This could be part of the natural gas RAB (in the short-term), a stand-alone hydrogen RAB, or individual RABs for specific pipeline projects could be created. A competitive framework to decide which projects are supported by regulated returns could be incorporated into delivery of the business model. |
| 12. Who is the delivery body? | If the natural gas RAB is amended to incorporate hydrogen (albeit temporarily), the delivery body for this would be **Ofgem**. Similarly, the creation of a new hydrogen RAB would likely fall to Ofgem in the long run, with **BEIS or a counterparty** potentially playing a key role for early projects. |

Please refer to the transport chapter of the main consultation for further details on transport business model design, including consideration of business model design to support different ways of transporting hydrogen (as a gas or a carrier, e.g., ammonia) and hydrogen transport onshore and offshore.

**Storage**

Like the market barriers section, this table has been completed in full for storage so that it can be read in isolation. This means there may be some duplication with the conclusions for transport business model design above. As there are more plausible options for storage business model design, we don't have initial conclusions on some questions around delivery which we were able to answer for transport. The storage chapter of the main consultation provides further detail on storage business model design.

| | |
|---|---|
| 1. What is the aim of the business model? | Policies and business models focused on the wider hydrogen economy, e.g., end-user led subsidies and obligations should increase the demand for hydrogen storage but wouldn't necessarily lead to investment in strategic and long-term storage infrastructure that would support multiple users. Additionally, business models in the wider supply chain would not provide sufficient certainty for storage providers.<br><br>Production or end-user led business models with support provided for storage would allow site-specific storage to be built. On the downside, relying solely on producer or end-user led business models may result in lots of smaller-scale storage infrastructure when larger-scale storage could have serviced needs more efficiently. Only supporting storage necessary for specific production sites could have this result. However, a business model targeted at hydrogen use in power (an end-use) could be effective at enabling the efficient growth of hydrogen storage for electricity system balancing but this wouldn't support the wider use of hydrogen across the economy.<br><br>A **storage-led business model** is preferable to production or end-user led business models alone as this is more likely to allow larger-scale and strategic storage to be built which can service multiple producers and users. Alongside this, **initial support for small-scale storage via production led business models** is necessary for initial growth of the hydrogen economy. **Policies** with the aim of driving market development and use of storage infrastructure could be incorporated into a storage-led business model or delivered alongside a business model. The business model would be designed to overcome the key risks to enable investment while additional policies could drive efficiency and value for money by encouraging use of the infrastructure. |

| | |
|---|---|
| 2. What type of business model is suitable? | A key driver of whether the system will be a monopoly or not is system complexity. In the early stages of hydrogen economy growth, hydrogen storage will likely be integrated with specific production projects and will not have a monopoly pull. However, in later stages of hydrogen economy growth, if there are multiple producers and users relying on the same storage infrastructure, storage could exert a monopoly pull. Underground storage is constrained geographically as it can only be built in suitable sites – e.g., salt caverns or depleted gas fields. Potential storage sites and the role storage plays in system balancing will affect whether storage has monopolistic qualities.<br><br>If storage will have monopolistic qualities, then a business model and commercial framework delivered indefinitely by **economic regulation** would be preferable. In this instance, regulated returns could protect users in the absence of competition in the long-run in addition to enabling growth and investment in the short-term. However, if in the future storage would operate competitively and on a merchant basis, **contractual payments to storage providers** over e.g., 10-20 years could be more suitable. The time-limited contractual payments would overcome the initial market barriers and enable storage sites to be built. Following this (and in the absence of a monopoly), competition should act to lower prices, increase efficiencies, and protect users. |
| 3. What are the key market barriers the business model is trying to overcome? | With small-scale storage linked to specific production sites and end users, the main market barrier is the high price to get hydrogen that's been produced to an end user using any necessary storage infrastructure (to counter mismatch in supply and demand). Hydrogen will mainly be competing against natural gas so needs to be cost competitive with gas at the point of use. This is a market price risk and policies would need to be designed to make the cost of production plus storage competitive. Where storage is linked to a specific production and demand site, supply and demand uncertainty is less of a barrier.<br><br>For larger storage infrastructure, **demand uncertainty is the main market barrier**, described in detail in the above section. Additionally, the **up-front costs** for larger-scale storage sites will be very high and these costs cannot be passed onto hydrogen users while there are no or few hydrogen consumers.<br><br>For new and unknown storage technologies, technological uncertainty will be the main market barrier. Market barriers will change as the hydrogen economy grows and the design of the business models will need to be adaptable. |

| | |
|---|---|
| 4. Who are the likely investors and operators? | Potential investors and operators for hydrogen storage include **companies currently operating gas storage sites** who plan to repurpose these for hydrogen storage. Proposed projects in the public domain are summarised in the pipeline evidence.<br><br>More evidence on likely investors, particularly in any innovative storage technologies is needed. This is something we are hoping to gather from this consultation. |
| 5. What type of costs need price support? | If there are potential investors in innovative storage technologies, these may benefit from upfront DEVEX and CAPEX support to overcome the barrier of technological uncertainty. Providing DEVEX and CAPEX support could also reduce the overall costs of the project and therefore decrease price support needed and lower costs to the consumer and taxpayer.<br><br>Some price support for storage will be provided by the production Hydrogen Business Model (if it is deemed to be necessary, affordable and value for money) for some initial projects. For larger storage infrastructure, the key barrier is supply and demand uncertainty and therefore **revenue support will be necessary.** Capital support alone is unlikely to incentivise investment in storage infrastructure as this will not alleviate the supply and demand barrier. Revenue support should also minimise the risk of stranded assets. |
| 6. How should price support be delivered? | Focusing on larger-scale storage, we predict revenue support will be needed to overcome volume risk because of demand uncertainty. Because storage could be delivered by a contract or regulated returns, **availability-based payments**, a **government offtake back/front stop,** a **regulated asset base** or a **sliding scale support mechanism** are all plausible options. |

The options for business model design and delivery are considered further in the main consultation – please see the transport and storage chapters respectively. As our evidence base on hydrogen transport and storage grows and we make decisions on the design of business models, we will conduct more analysis on the specifics of the above questions. For example, this will include analysis on the detail of potential price support design, including how to set appropriate support levels. This evidence and analysis will be included in future consultations on transport and storage business model design.