matrix.

Northern Ireland
Science Industry Panel

Foresight Study

Northern Ireland's Future Hydrogen Demand and Capability

2022 report

frontier economics

Contents

Figures

Foreword

We are living through times which are witnessing extraordinary pressures on both the environmental sustainability of our planet and the maintenance of affordable energy supplies. Under these circumstances the emergence of innovative approaches to provide clean, sustainable energy represent both an existential imperative and an opportunity to drive prosperity.

Harnessing the potential of green hydrogen production and use is not without its challenges, but Northern Ireland is uniquely placed to act as an engine for innovation and a proofing ground for technologies that make the production and use of green hydrogen a reality. Unique infrastructural features such as a modern natural gas pipeline network, large scale gas storage capacity and a manageable collection of stakeholders can be brought together towards a common goal harnessing the potential of this unique alternative energy source.

Northern Ireland is already on the front foot in terms of utilising onshore wind power and other sources of renewable energy with over 40% of NI's power coming from these sustainable sources. But there is yet more to gain. Many kilowatt-hours of energy that could be utilised from onshore wind power are lost overnight as power is produced but not drawn down due to low demand, a phenomenon known as curtailment. Green hydrogen represents an opportunity to convert this energy, produced during periods of curtailment, into a storable medium so that it can be introduced back into the system at a later date by burning hydrogen. A process that produces only water as an emission.

The challenges in turning this potential into reality are not just technical. There currently does not exist a functioning market for hydrogen. There is also a lack of appropriate regulation around the distribution and use of the fuel. There is therefore an awful lot to be done by legislators and policy makers in order for there to be a permissive environment for a hydrogen economy.

Returning to the potential of green hydrogen, if we act quickly and decisively to create an environment where the research talent and business acumen available in Northern Ireland can combine with the existing infrastructure and utility provision we have the opportunity, in uncertain times, to provide security of energy supply, affordable fuel to the consumer and make significant progress towards our net-zero carbon targets.

Dr Robert Grundy, FRSB
Chair of Matrix and Chair of the Steering Group

executive summary

Executive Summary

Matrix[1] commissioned Frontier Economics to articulate the following:

- A vision for the green hydrogen economy in Northern Ireland, considering supply, demand and export potentials and an assessment of barriers and enablers that may need to be overcome or enhanced to ensure the sectors development.
- An action plan to overcome these barriers and foster enablers.
- An assessment of potential wider impacts on growth, employment and skills in the green economy.

A vision for the Green Hydrogen Economy

In March 2022, the Northern Ireland Assembly passed climate change legislation committing the region to Net Zero carbon emissions by 2050, bringing its ambition in line with that of the UK as a whole[2,]. In December 2021, the Department for the Economy (DfE) published the Northern Ireland Energy Strategy which sets out the pathway to deliver the 2050 vision of net zero carbon and affordable energy.

Hitting these targets will require the transformation of entire energy systems and tackling emissions from hard-to-electrify sectors. As a means of accomplishing this, the Energy Strategy recognises the potential role of hydrogen. By 2050, the strategy finds that hydrogen could make up 19-24% of final energy consumption.

The research and stakeholder engagement undertaken for this report aligns with the Northern Ireland Energy Strategy in suggesting that Northern Ireland has the potential to leverage its wind potential and develop a green hydrogen producing sector. Doing so could limit curtailment and favour further wind expansion. Additionally, Northern Ireland has the ability to capitalise on its unique infrastructural features such as a modern natural gas pipeline network and large-scale gas storage capability to produce, store and utilise green hydrogen.

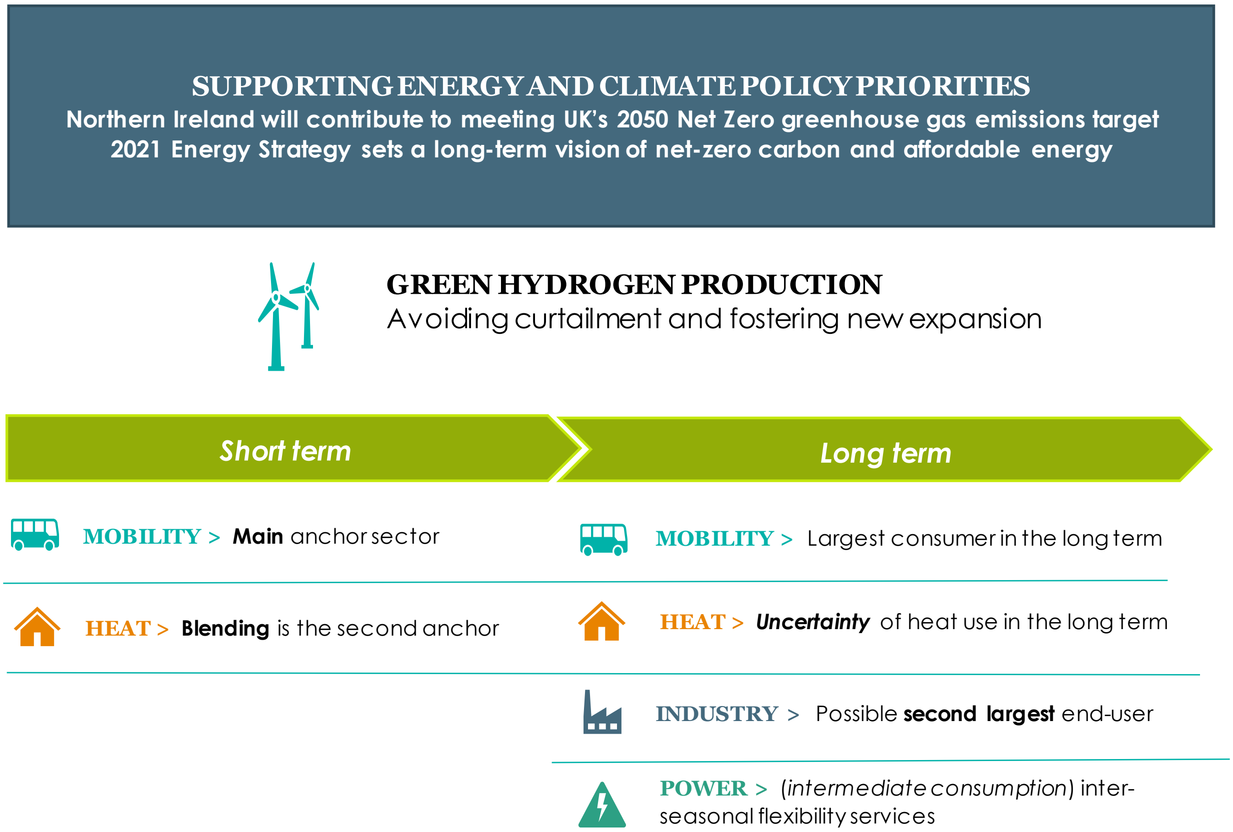
Demand from mobility and blending providing the near-term anchors to kick-start the sector in earnest. In the longer-term, mobility and industry are likely to be the largest low-carbon hydrogen consuming sectors whilst demand in heating is

1 Matrix, The Northern Ireland Science and Industry panel, is an industry led engagement panel advising government and informing academia and industry on the commercial exploitation of R&D and science and technology. https://matrixni.org/

2 http://www.niassembly.gov.uk/assembly-business/legislation/2017-2022-mandate/non-executive-bill-proposals/climate-change-bill/

uncertain. Leveraging on its large storage potential at Islandmagee, low-carbon hydrogen could have a role in the power sector providing inter-seasonal flexibility services.

Figure 1. Hydrogen's role for decarbonising Northern Ireland



Source: Frontier Economics

Stakeholder engagement[3] suggested the importance of developing specialisms linked to the development of a green hydrogen economy. Contributors particularly highlighted the intention to harness first mover advantage in developing the following specialisms:

- Production of synthetic liquid fuels to decarbonise the agriculture sector.
- Green ammonia production to decarbonise the maritime sector.

[3] Frontier Economics conducted ten one-to-one interviews, one in-person workshop and two virtual workshops to engage with the steering and stakeholder groups for this study. For further information on the stakeholder engagement undertaken, please refer to section 2 and Annexes A and B.

- Export of specific technological developments.
- Export of hydrogen equipment.

Our assessment suggests the greatest potential for Northern Ireland relates to technology development (to the point of niche market development, not full commercialisation[4]). This specialism aligns with the Energy Strategy objective to grow the green economy and has the potential to support the main objective of decarbonisation.

Action Plan for Green Hydrogen

We have recommended a set of actions building on international experience and stakeholder consultation. Our recommendations take a long-term perspective of the sector's development, out to 2050. We expect that in this timeframe the sector will evolve, moving along an industry's lifecycle: introduction, growth and maturity.

The ***near-term*** priority is getting the sector up and running. To achieve this objective, we recommend:

- **Whole-system Planning**, an approach comprehensively considering all energy vectors to decide the most efficient balance of energy and optimise infrastructure, therefore minimising the costs of decarbonisation.
- Ensuring **Public Funding** is available for the sector to bridge the cost gap between green hydrogen and incumbent fossil fuels and reduce the burden of appliance adaptation costs for end-users. We recommend ensuring public support allocation favours coordination, and therefore builds on whole-system planning and prioritises projects considering more than one stage of the value chain.
- Considering **Regulatory Adjustment** to enable blending, network adaptation/roll-out, certification such that it is possible to capture end-users' willingness to pay for the green characteristics of Northern Irish hydrogen and to strengthen renewable investment.
- Implementing a **Hydrogen Governance Body** to align responsibilities and capabilities of relevant government bodies in driving and implementing the sector's development. We recommend this body includes a consultation body with key stakeholders in the sector, with the dual purpose of favouring cohesion

[4] Full commercialisation includes activities such as machinery assembling line and associated deployment of front-base / client service facilities.

among stakeholders and communication between them and the government. A monitoring office would further ensure the plans adapt to the sector's needs.

- Ensuring the **Hydrogen Catapult** identified in the Energy Strategy is established soon ensuring Northern Ireland keeps up pace with global efforts and demand for further progressing hydrogen technologies.

In the ***mid-term***, actions would focus on maintaining growth. To this end, we recommend:

- **Harnessing the storage potential** and related services to the power sector, if efficient to do so,
- **Exploring additional growth enhancing actions** – like quotas – only to the extent that trade competitors do so. Otherwise, Northern Ireland's competitiveness would be harmed.
- **Refining infrastructure regulation**, tailored to the sector's need.

In the ***long-term***, priorities are ensuring markets work well, this requires:

- **Removing cross-sector distortions** – Moving away from dedicated support mechanisms and subsidies.
- **Carbon price driving decisions** - ensuring a cross-sector single price drives energy choices.

Figure 2. Summary Action Plan

NEAR TERM

Horizon 1 - Getting the sector up and running

WIDE-SYSTEM PLANNING

Whole systems entity

- Optimise carrier selection and infrastructure
- Inform location decisions for hydrogen production
- Enhance sector coupling.

ALLOCATE SUPPORT

- Favouring coordination
- Understand the cost drivers, introduce support mechanisms to lower the cost gap for production and demand.
- Tailored to NI's economy

REGULATORY ADAPTATION

- Enable blending
- Prepare network adaptation/roll-out
- Drive willingness to pay (certification)
- Encouraging RES investment

HYDROGEN GOVERNANCE BODY

Relevant government representatives, in cooperation with relevant partners and experts to monitor and adapt plans

HYDROGEN CATAPULT

Connecting businesses with research and academic communities to help them adopt, develop and exploit their innovation.

MEDIUM TERM

Horizon 2 – Enhancing further expansion

HARNESSING STORAGE POTENTIAL

Following wide-system analysis, storage potential at Islandmagee paired with hydrogen compatible turbines could provide **seasonal flexibility**.

ENCOURAGING GROWING MARKETS

For example, via obligations or quotas, assessing if other jurisdictions (with trade relations or competitors) are doing so.

REGULATORY ADAPTATION

Ensuring framework favours new/ H2 adaptation addressing any market power issues.

LONG TERM

Horizon 3 – Ensure markets work

REMOVING CROSS-SECTOR DISTORTIONS

Moving away from dedicated support mechanisms/ subsidies

CARBON PRICE DRIVING DECISIONS

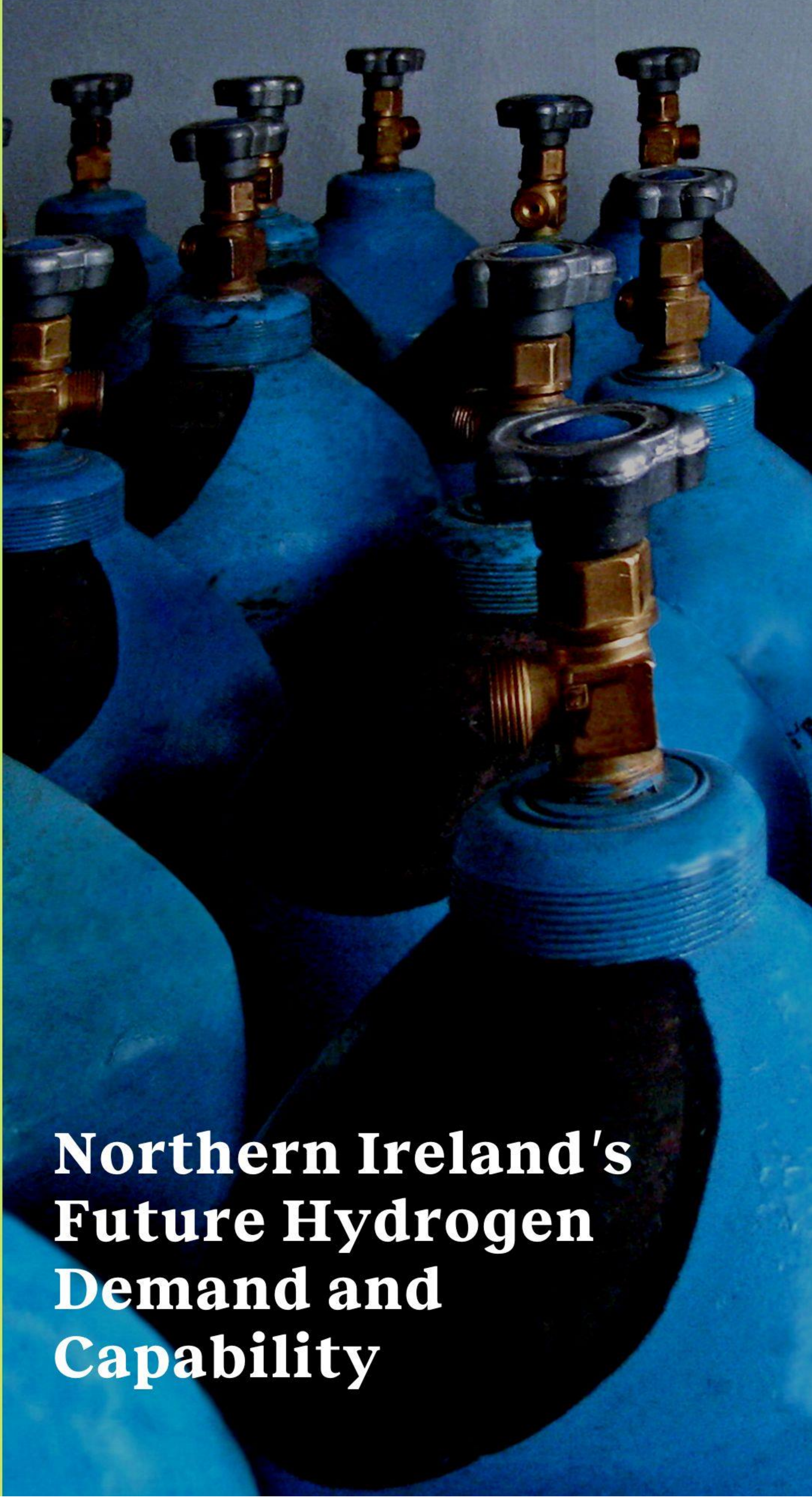
Pan-sectoral global carbon prices to drive consumption decisions.

Wider impacts on the economy

In this report we have reviewed the impact that developing a green hydrogen economy could have on the wider economy and determined that green hydrogen has the potential to become a true green engine behind growth in the wider green economy.

- **Economic Impact -** Sustainable economic growth requires an appropriate green engine to fuel all economic activities. Energy supply is fit for this purpose when it is sustainable, secure and competitive. Integrating green hydrogen in the energy matrix enhances these three criteria. Building on a whole-system planning, green hydrogen integration enables cost-efficient decarbonisation of energy supply. It also enhances security of supply, enabling Northern Ireland to rely on a larger share of domestic energy production and a more diversified portfolio of trading partners.
- **Jobs -** Green hydrogen integration also has the potential to support jobs by contributing to the competitiveness of the economy. By creating new economic activities, developing this sector also can directly support jobs, though we have not assessed substitution and leakage effects in our jobs analysis.

  According to the UK Hydrogen Strategy, the UK hydrogen economy could support over 9,000 jobs by 2030 and up to 100,000 jobs by 2050. Proportionately, the jobs supported in Northern Ireland could be 555 in 2030 and 3,403 in 2050.
- **Skills -** For those jobs to materialise, it is essential that workers are equipped with the right skills. We recommend a process of identifying skills gaps and developing and disseminating content to bridge these gaps. Ensuring this process remains timely, such that updates follow monitoring, ensures skills adapt to the sector's needs and support continued job creation.



Northern Ireland's Future Hydrogen Demand and Capability

1 Introduction

In March 2022, The Northern Ireland Assembly passed climate change legislation committing Northern Ireland to Net Zero carbon emissions by 2050, bringing its climate ambition in line with that of the UK as a whole[5]. Northern Ireland's contribution to the UK 2050 Net Zero greenhouse gas emissions target will require a transformation of its energy system.

Decarbonisation in all sectors will be required, including those which cannot be easily electrified, for example in the high heat industry and heavy transport. Using low-carbon hydrogen may help decarbonise, reduce the reliance on imports, and bring security of supply benefits. There are also wider opportunities for innovation and economic growth associated with the development of new technologies and industries related to a hydrogen economy.

Globally, significant opportunities are also opening up in relation to low-carbon hydrogen. According to the Hydrogen Council, at the beginning of 2021, over 30 countries had released hydrogen roadmaps[6]. Opportunities for the export of low-carbon hydrogen, or of the skills and technologies associated with a green hydrogen economy are likely to result.

The potential contribution of low-carbon hydrogen on a path to Net Zero has been reflected in Northern Ireland's recent Energy Strategy[7]. This strategy particularly recognises the substantial economic opportunities associated with hydrogen, both in terms of attracting investment into the local economy and in positioning local industries to take advantage of the global opportunities associated with low-carbon hydrogen. These opportunities are aligned with the wider policy framework.[8]

Low-carbon hydrogen can be produced in several ways. However, given its substantial renewable resources, and a lack of easy access to planned carbon capture and storage infrastructure, the focus in Northern Ireland is largely on green hydrogen[9] (Figure 3), or any other technology harnessing the region's renewable

5 http://www.niassembly.gov.uk/assembly-business/legislation/2017-2022-mandate/non-executive-bill-proposals/climate-change-bill/

6 Hydrogen Council (2021), *Hydrogen Insights*,

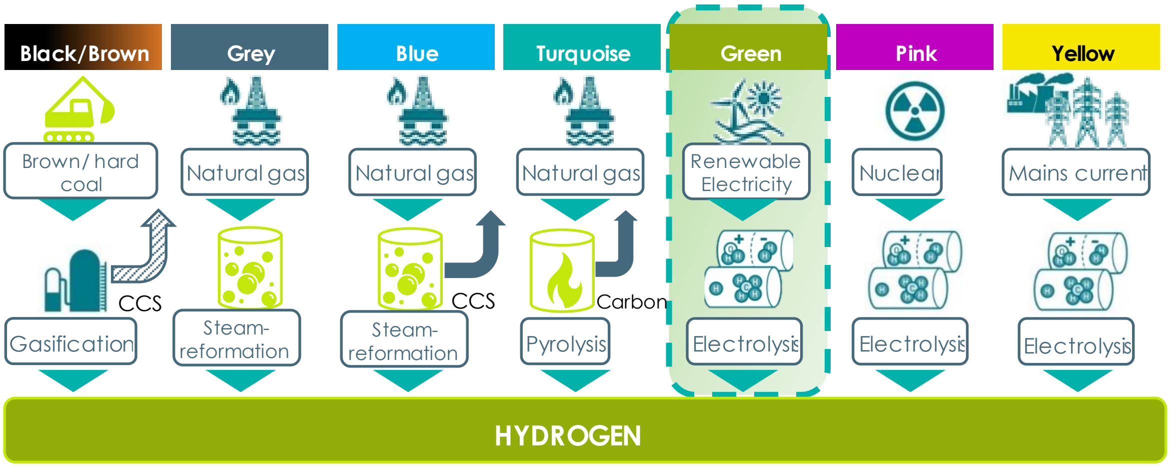
7 DfE (2021), *Energy Strategy - Path to Net Zero Energy*.

8 In particular, Northern Ireland's Skills Strategy, Industrial Strategy and Innovation Strategy.

9 Frontier (2021), Hydrogen Options for Northern Ireland

energy sources and that does not require low cost access to carbon capture and storage.[10]

Figure 3. Green hydrogen within the hydrogen rainbow



Source: Frontier Economics

Note: This diagram presents a non-comprehensive selection of hydrogen production methods, largely focusing on those where the industry has developed a colourful convention

1.1 Aims of this work

In the context of developments in Northern Ireland, the rest of the UK and globally, Matrix[11] has commissioned Frontier Economics to articulate the following out to 2050 (See Figure 4):

- A vision for the green hydrogen economy in Northern Ireland.
- Barriers and enablers that may need to be overcome or enhanced to ensure the sector's development.
- An action plan to overcome these barriers and foster enablers.
- An outline of wider impacts on the economy, with a focus on employment and skills in the green economy.

[10] For example, hydrogen produced by gasification of biomass could be paired with a process to solidify carbon, getting around issues of lack of carbon capture and storage.

[11] Matrix is an industry led panel advising the government and informing academia and industry on the commercial exploitation of R&D and science and technology. https://matrixni.org/

Figure 4. Overview of the project

Source: Frontier Economics

1.2 Overview of this report

This report presents our analysis as follows:

- **Section 2** describes the stakeholder engagement that we have undertaken for this project.
- **Section 3** discusses the objectives for developing a hydrogen economy in Northern Ireland.
- **Section 4** describes the barriers and enablers to achieve this vision.
- **Section 5** presents an action plan.
- **Section 6** concludes, discussing the impact on the wider economy, with a focus on skills and jobs.

2 Stakeholder engagement

Stakeholder consultation is at the core of our analysis, complemented with desk research.

At the start of this work, we identified a range of key stakeholders to engage with, some of which are part of the study's steering group (see Annex A) that Matrix has brought together. These are set out in Figure 5.

Figure 5. Stakeholder and steering groups

Production, storage & technologies

- B9 Energy and storage
- Catagen
- Clean Power Hydrogen Group (technologies)
- ESB
- SSE
- Energia
- TK Renewables
- Islandmagee energy storage

Networks

- Firmus
- Phoenix Natural Gas
- PTL
- GNI UK
- SONI
- SGN
- Mutual Energy
- NIE

Retail/end-users

- Wrightbus
- Translink
- Belfast Maritime Consortium

Regulators and policy

- Utility Regulator
- Department for the Economy
- Department of Finance
- Department for Infrastructure
- Department of Agriculture, Environment and Rural Affairs
- Office of the Northern Ireland Executive in Brussels
- Northern Ireland Water

Research / cross-industry advice

- Energy Systems Catapult
- Challenging Ideas
- Centre for Advanced Sustainable Energy
- Hydrogen Safety Engineering and Research Centre
- Bryson Centre
- Northern Ireland Advanced Composites and Engineering Centre
- Belfast Metropolitan College
- National University of Ireland Galway

Steering Group

- NI Water
- Dublin City University
- MJM Renewables
- Core Systems
- Strategic Investment Board
- Invest Northern Ireland
- Northern Ireland Electricity Networks
- National University Ireland, Galway
- Queen's University Belfast
- Department for the Economy

Our stakeholder engagement has taken two forms:

- Ten one-to-one interviews with stakeholders. These interviews were structured based on the Seven Questions framework from the UK Government's Futures Toolkit[12] (Figure 6).
- A series of three workshops, where attendees had the opportunity to contribute to the discussion in the workshop forum, via a live portal (Mentimeter,[13] when having an in-person session) or in the meeting chat, and via follow up emails to us:
    - An in-person workshop on March 22, 2022, on barriers and enablers to develop a green hydrogen economy in Northern Ireland. With 27 attendees, we held this in cooperation with a complementary study from the Advanced Manufacturing Innovation Centre (AMIC)[14]
    - A virtual workshop on April 22, 2022, with 58 attendees, on a proposed action plan to develop the sector.
    - A virtual workshop on May 19, 2022, with 16 attendees, discussing the wider impacts on the economy, with a focus on skills and employment.

[12] Government Office for Science (2017) *The Futures Toolkit*

[13] www.menti.com

[14] AMIC has commissioned a Hydrogen Scoping Study with the objectives of mobilising key stakeholders and forming a hydrogen task force for Northern Ireland, creating a hydrogen roadmap for Northern Ireland – in terms of technology and skills – focused on the short-to-medium term and defining options for a technology accelerator.

Figure 6. Seven Questions on Hydrogen futures

1. What is your **vision** for a hydrogen business?
2. What are the **critical factors** that would need to be in place for you to invest in green hydrogen?
3. What could go **wrong** if you try and achieve this vision?
4. What could be the **barriers** for a hydrogen business? What could be the **enablers**?
5. What **actions** do you consider necessary to tackle the barriers identified? What actions could foster the enablers? What **lessons from the past**, for example from the expansion of renewable sources, could inform these actions?
6. What actions do you consider that should be **prioritised**?
7. What would you do if you had absolute authority in this area?

Source: Frontier Economics, based on the Seven Questions Framework: Government Office for Science (2017)

The analysis in the next sections builds on stakeholder consultation and our desk research.

3 Objectives for developing a hydrogen economy in Northern Ireland

Understanding the objectives for developing a green hydrogen economy in Northern Ireland is the starting point for assessing the potential barriers and enablers and developing a corresponding action plan.

Policy priorities articulated in the Energy Strategy and stakeholder engagement, points at two potential objectives: supporting decarbonisation and developing specialisms (summarised in Figure 7 below).

Figure 7. Objectives for a green hydrogen sector in Northern Ireland

Supporting decarbonisation

Ensuring green hydrogen integration to enable decarbonisation.

Developing specialisms

Harness first movers advantage to develop specialisms ensuring jobs and skills creation.

Source: Frontier Economics

We engaged in desk research to assess these objectives, as described in the following sub-sections.

3.1 Supporting decarbonisation

Supporting decarbonisation is the core reason for the development of a hydrogen economy. We conducted desk research to further understand the characteristics of potential hydrogen supply and demand in Northern Ireland.

3.1.1 Policy priorities for the energy sector

Northern Ireland's December 2021 Energy Strategy sets out plans for how Northern Ireland can move to a Net Zero economy[15]. This strategy sets three goals:

1 **Energy efficiency:** Deliver energy savings of 25% from buildings and industry by 2030.

2 **Renewables:** Meet at least 70% of electricity consumption from a diverse mix of renewable sources by 2030.

3 **Green Economy:** Double the size of the low-carbon and renewable energy economy to a turnover of more than £2 billion by 2030.

The second two of these goals are highly relevant to the development of green hydrogen in Northern Ireland.

- **Focus on renewables**. Northern Ireland already has high levels of existing renewables (mainly onshore wind). Just under 50% of electricity in Northern Ireland was generated from renewable sources in 2021[16]. There is strong potential to grow this sector, and in March 2022, the Northern Ireland Assembly voted to sign up to an 80% renewable electricity target in 2030, as part of the Climate Bill[17]. A focus on developing renewable electricity supports a vision for green hydrogen production in Northern Ireland: a highly intermittent electricity supply could both drive a need for hydrogen as a storage vector and could also provide a cost-effective source of electricity for green hydrogen production (e.g., through curtailed wind).
- **Focus on developing a Green Economy**. Hydrogen is central to the Energy Strategy's plans to develop a green economy. A key action of the Energy Strategy is to implement a Hydrogen Catapult in partnership with academia. This Catapult will aim to be a centre of excellence in research and innovation and to bring together key players across the hydrogen economy. The strategy also sets out opportunities in relation to the renewable electricity potential, engineering

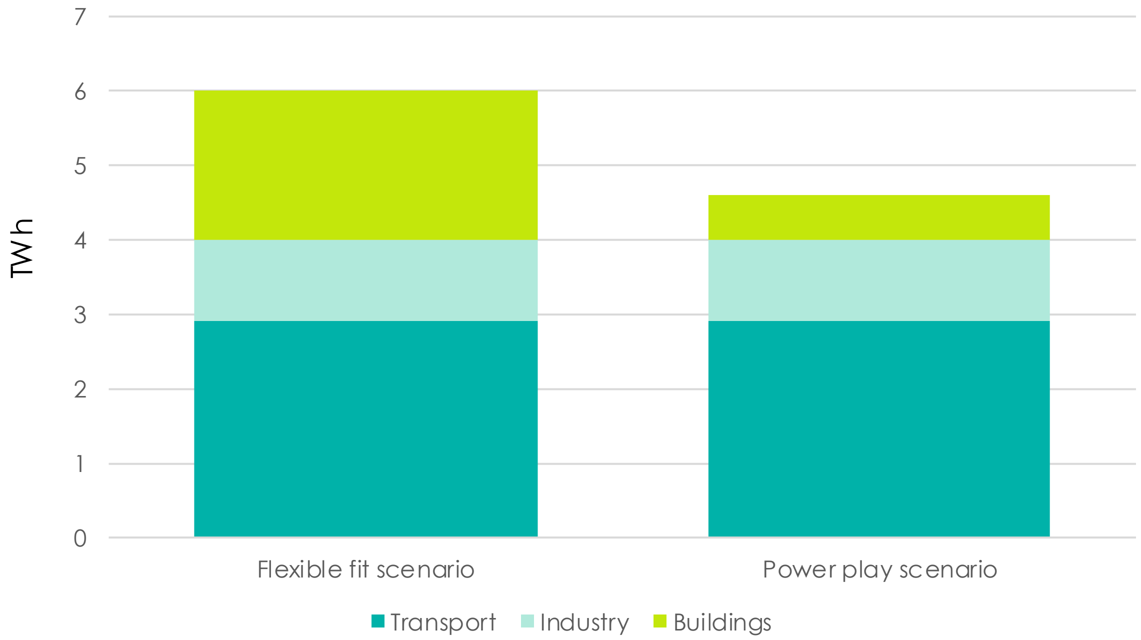
[15] DfE (2021), Energy Strategy - Path to Net Zero Energy

[16] DfE (2021), Electricity Consumption and Renewable Generation in Northern Ireland: Year Ending December 2020

[17] https://renewableni.com/renewableni-success-at-achieving-80-by-30-climate-bill-target/

capabilities, early momentum (due to projects already in development), public sector leadership, a modern gas network and a world-leading research centre in hydrogen safety, HySAFER. In terms of the demand side for low-carbon hydrogen, the Strategy sees a significant role for transport and industry, with greater uncertainty around the role in heating buildings (Figure 8).[18] Overall, the Strategy projects that hydrogen could meet 19%-24% of the total energy demand in 2050.

Figure 8. Energy Strategy's scenarios for hydrogen demand in TWh in 2050, by sector



Source: DfE (2021), The Path to Net Zero Energy

[18] This is consistent with the findings of earlier work by Frontier Economics for NIE. Frontier (2021), [Hydrogen Options for Northern Ireland](),

3.1.2 Further desk research on hydrogen's integration in the energy matrix

Our research considers production and storage capabilities as well as demand by sectors.

Low-carbon hydrogen production and storage

Our wider desk research supports a focus on green hydrogen production, rather than blue hydrogen as considered in the UK Hydrogen Strategy[19], which would require methane input fuels and access to Carbon Capture, Utilisation and Storage (CCUS) infrastructure. This is due to:

- the high level of planned renewables in Northern Ireland (described in policy priorities for the energy sector),
- the stated aim in the strategy to reduce Northern Ireland's reliance on fossil fuels and become more self-sufficient, strengthening Northern Ireland's energy security,
- the lack of easy access to planned CCUS infrastructure (Box 1) in the near term, and
- the residual emissions associated with blue hydrogen production, which may make it difficult to accommodate in a Net Zero economy. This is especially relevant in Northern Ireland, where there are already likely to be high levels of residual emissions from agriculture[20].

[19] BEIS (2021), UK Hydrogen Strategy

[20] CCC (2022), Letter: Northern Ireland's Climate Change Bill

Box 1. Access to CCUS infrastructure in Northern Ireland

- **Local CCUS infrastructure.** While there are potential CO_2 storage sites at Rathlin, Portpatrick/Larne and Peel basins on the east coast of Northern Ireland and at Lough Neagh, these sites are not being developed at present[21].
- **Access to HyNet.** It may be possible to ship carbon to UK carbon storage sites (in particular, to the HyNet Cluster on the west coast of GB, referenced in the Energy Strategy). However, this would add costs. The additional costs of shipping CO_2 could be around £10-20/tCO_2. and on top of this, additional investment could be required at the cluster to allow shipped CO_2 to be accepted into the infrastructure[22].

Northern Ireland's large potential for gas storage in a salt cavern at Islandmagee, further suggests that hydrogen could support the energy sector by compensating for the intermittency of renewable sources and the inter-seasonal variation of energy demand[23].

21 Lewis et al. (2009). Assessment of the potential for geological storage of carbon dioxide in Ireland and Northern Ireland. Energy Procedia, 1(1), 2655-2662.

22 CCC (2020), Letter from Lord Deben Climate Change Committee to Edwin Poots MLA

23 ENTSOG (2020) *Ten year development plan (p. 768)*

Low-carbon Hydrogen demand

At a UK level, low-carbon hydrogen is expected to play a key role in tackling emissions from hard to decarbonise sectors, particularly the high heat industry and heavy transport[24]. The role of hydrogen in heating buildings is less certain, with BEIS planning to decide on this in 2026. Table 1 presents expected demand progression through time.

Table 1. Expected low-carbon hydrogen demand in the UK

Timeline	Early 2020s	Mid 2020s	Late 2020s	Mid-2030s onwards
Expected demand	• Some transport (buses, early HGV, rail & aviation trials) • Industry demonstration • Neighbourhood heat trial	• Industry applications • Transport (HGV, rail & shipping trials) village heat trial • Blending (tbc)	• Wide use in industry power generation & flexibility; transport (HGVs, shipping) • Heat pilot town (tbc)	• Full range of end users including steel; power system; greater shipping & aviation • Potential gas grid conversion

Source: Adapted from BEIS (2021) UK Hydrogen Strategy

Demand in Northern Ireland is likely to have some commonalities but also some divergences to this.

- **Transport:** As in the rest of the UK, low-carbon hydrogen is likely to be important in the heavy transport sector. Fuel cells are widely considered to be a useful decarbonisation option for heavy-duty transport because there are few alternative options.[25,26,27] Northern Ireland already has activity in this area: the Translink/Wrightbus/Energia project is trialling hydrogen buses in Belfast[28]. The fact that Translink is the single provider of mass public transport services in Northern Ireland could favour green hydrogen take-up in this segment. As a government-

[24] BEIS (2021), *UK Hydrogen Strategy*

[25] CCC (2020), *Sixth Carbon Budget* includes scenarios with up to around 80% of HGV as FCEV in 2035 in their most ambitious hydrogen scenario

[26] EC (2020) estimates that around 25% of HGVs and 20% of LGV will be FCEV in 2050

[27] Navigant (2019) estimates up to 50% of HGV and 10% of LGV will be FCEV in 2050

[28] Translink/Wrightbus/Energia launched three hydrogen fuel cell double decker buses in 2020 funded by the NI Department for Infrastructure and OZEV. They are powered by green hydrogen produced by an on-shore North Antrim windfarm. The overall capital investment is around £4 million.

owned company, decarbonisation commitments are fully aligned to its corporate decisions.[29]

- **Industry.** Unlike in GB, Northern Ireland does not have major clusters of heavy industry, requiring significant quantities of hydrogen for high heat processes. However, hydrogen is still likely to provide a useful role in the longer term, particularly given the lack of easy access to CCUS infrastructure (post combustion CCUS is one of alternative abatement options for heavy industry). The Climate Change Committee (CCC)'s Sixth Carbon Budget Analysis, based on a site-by-site analysis of industrial abatement, finds that from 8% - 25% of industrial energy demand in Northern Ireland could be met by hydrogen in 2050.[30]
- **Heating buildings.** The same uncertainty around the future role of low-carbon hydrogen in heating is in place in Northern Ireland as in the rest of the UK. In GB, over the past 20 years the Gas Mains Replacement Programme allowed the replacement of a share of old pipes with Polyethylene (PE) ones, which are easier to convert to hydrogen. However, there are still some parts of the grid that are not currently fit to carry hydrogen. While Northern Ireland's gas distribution network already consists primarily of PE pipes, it has significantly more customers that are currently off the gas grid (though the number of connections to the gas grid is growing)[31].
- **Power generation and system balancing.** Flexible generation is likely to be required alongside the high levels of renewables expected in Northern Ireland. Hydrogen can be used in gas-fired power plants, although the technology is not expected to be available before 2030. The main flexible low-carbon generation alternative would be to use biomethane instead of natural gas because easy access to CCUS is unlikely to be in place. Given the higher levels of renewables expected compared to the rest of the UK and the more limited alternatives for flexible generation, hydrogen in power may be important after 2030.
- **Blending.** Around 20% of hydrogen (by volume) could potentially be blended into the gas grid, without the need to make adjustments to the gas network infrastructure or swapping out household-level appliances. However, since hydrogen is less energy-dense than natural gas, carbon savings will be limited to around 7% even if the hydrogen is zero carbon. As in the rest of the UK, blending

[29] Attention should be paid to ensure decarbonisation decisions do not harm users. Given the monopolistic structure, significant cost increases passed on to fares would harm public transport users.

[30] CCC (2020), Sixth Carbon Budget

[31] The Utility Regulator, estimates that once GDNs complete the network development up to the end of the GD23 price control, approximately 65% of properties in Northern Ireland could have access to natural gas should they choose to connect to the network: Utility Regulator (2020)

may be helpful in the near term, but would not be consistent with Net Zero in the long term.

3.1.3 Summary of hydrogen's role for decarbonising Northern Ireland

Figure 9 summarises our analysis of hydrogen's role for supporting the decarbonisation of the Northern Irish economy. Leveraging on its wind potential, Northern Ireland could develop a green hydrogen producing sector. Doing so could limit curtailment and favour further wind expansion.

Green hydrogen consumption for mobility purposes and blending in the existing gas network could be the demand-side anchor for domestic production capabilities. In the long term, low-carbon hydrogen would continue supporting the decarbonisation of mobility, with transport being the main consumption sector. Hard to electrify industry could be the second largest low-carbon hydrogen end-consuming sector.

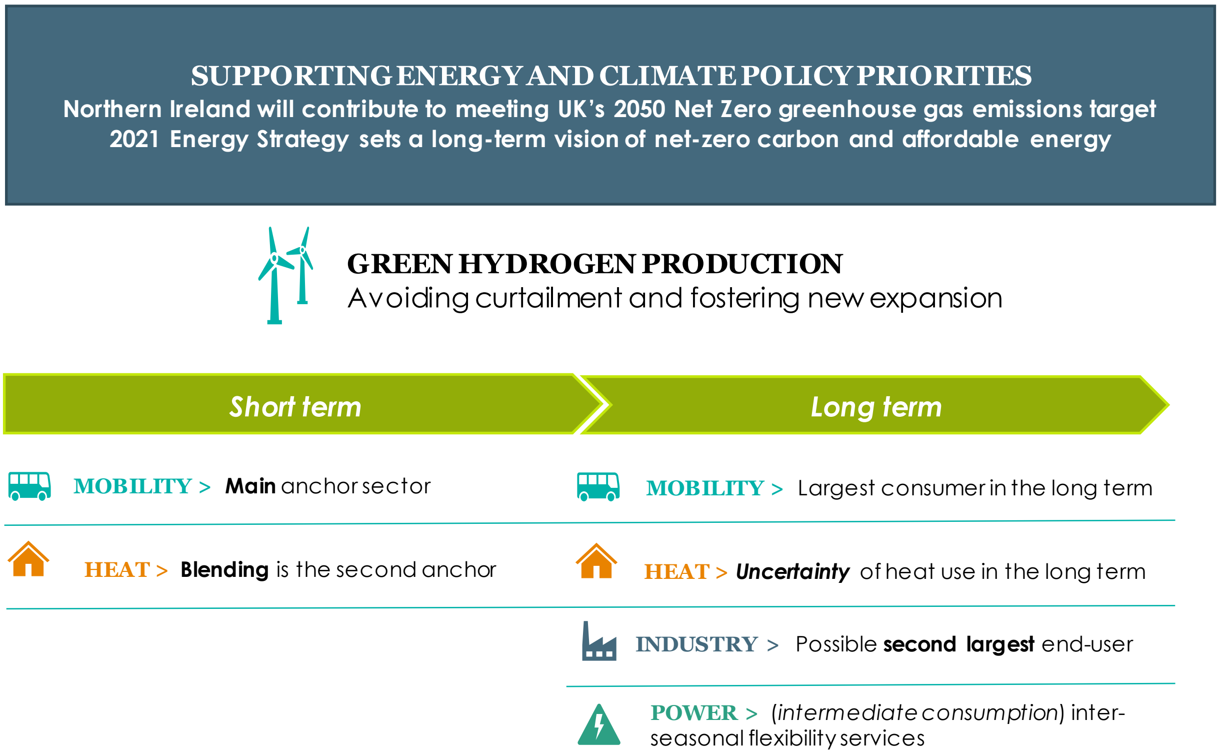
In the long term, there is uncertainty about the role of green hydrogen to decarbonise heating. This uncertainty largely relates to the potential of direct electrification to provide a more cost-effective decarbonisation opportunity.[32]

Green hydrogen would also have a role in decarbonising the power sector. By harnessing storage potential in the salt cavern at Islandmagee, hydrogen could provide flexibility services, most notably for inter-seasonal storage where hydrogen has the greatest competitiveness with respect to alternatives like batteries.

[32] Heat pumps, for example, could entail 285% efficiency rating attributable to their ability to withdraw more energy from the environment (whether the air, soil or water) than required in terms of operational power.

Approximately 30% of the energy is lost in the hydrogen transformation process (see Agora (2018) The Future Cost of Electricity-Based Synthetic Fuels. Page 12.

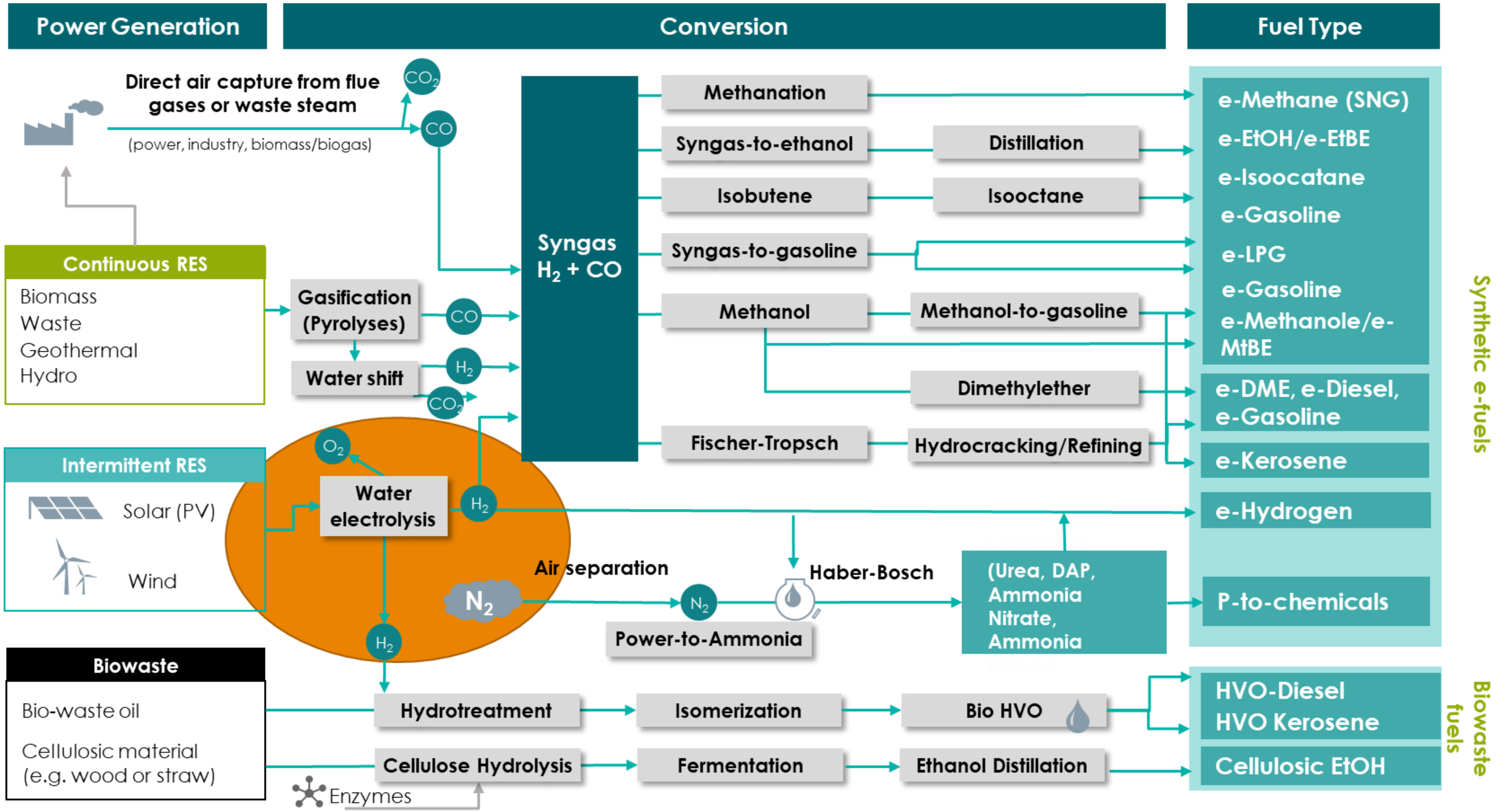
Figure 9. Hydrogen's role for decarbonising Northern Ireland



Source: Frontier Economics

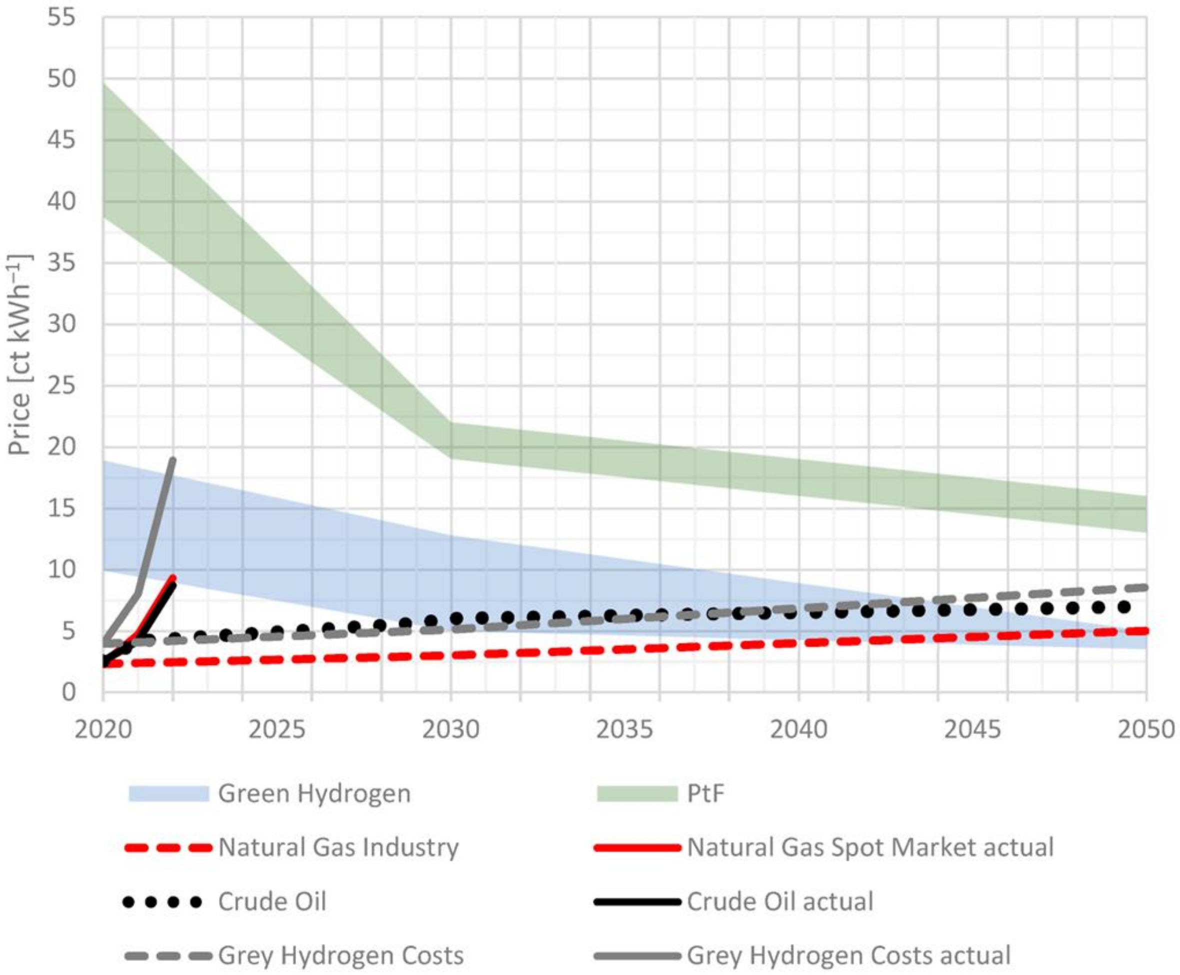
Our engagement found an ambition among stakeholders to extend efforts to develop a green hydrogen economy to other synthetic fuels (see Figure 10). We caveat that the Energy Strategy and our desk research focus on green hydrogen's role as the carrier enabling decarbonisation in the energy sector. Green hydrogen could be an input for additional green synthetic fuels. However, cost perspectives out to 2050 indicate that the likely future costs of synthetic fuels could be significantly higher than those of conventional fuels (see Figure 11).

Figure 10. Green Synthetic fuels from hydrogen



Source: Frontier Economics

Figure 11. Indications expected cost gap for green hydrogen and synthetic fuels (PtF)



Source: Schnuelle et al (2022)
Note: Assessment for Germany with price forecasts before the current energy crisis. PtF products refer to green synthetic liquid fuels.

We note that there is significant uncertainty over these cost projections, and that there may be certain applications in the Northern Irish economy where synthetic fuels are the most appropriate option (e.g., certain agricultural applications). We recommend monitoring developments to assess whether a strategy to develop a green hydrogen economy should expand to other synthetic products further down the line. Overall, we recommend prioritising the integration of synthetic fuels and any other clean energy carrier when identifying this as a cost-effective option to decarbonise the sector.

3.2 Developing specialisms

Stakeholders highlighted the intention to harness first mover advantage in developing the following specialisms with export orientation linked to the development of a green hydrogen economy in Northern Ireland:

- **Synthetic liquid fuels** production to decarbonise the agriculture sector.
- **Green ammonia** production to decarbonise the maritime sector.
- Export of **specific technological developments**.
- Export of **hydrogen equipment** (harnessing innovation – for instance, production equipment).

We have done a high-level assessment of these proposals to indicate potential areas for further development considering starting conditions and competitive advantage in international markets.

3.2.1 High-level assessment

We have assessed proposals against:

- **Starting conditions** linked to existing business models, including activities, resources, customer relations and channels in sectors that could orient towards the domestic market or exports.
- **Competitive advantage** related to the potential to compete internationally on quality/differentiation or costs (by deriving scale or exploiting resources).

Starting conditions and competitive advantage are related, yet one does not imply the other. Not all existing business models in Northern Ireland would have a competitive advantage in international markets to develop specialisms linked to a hydrogen economy.

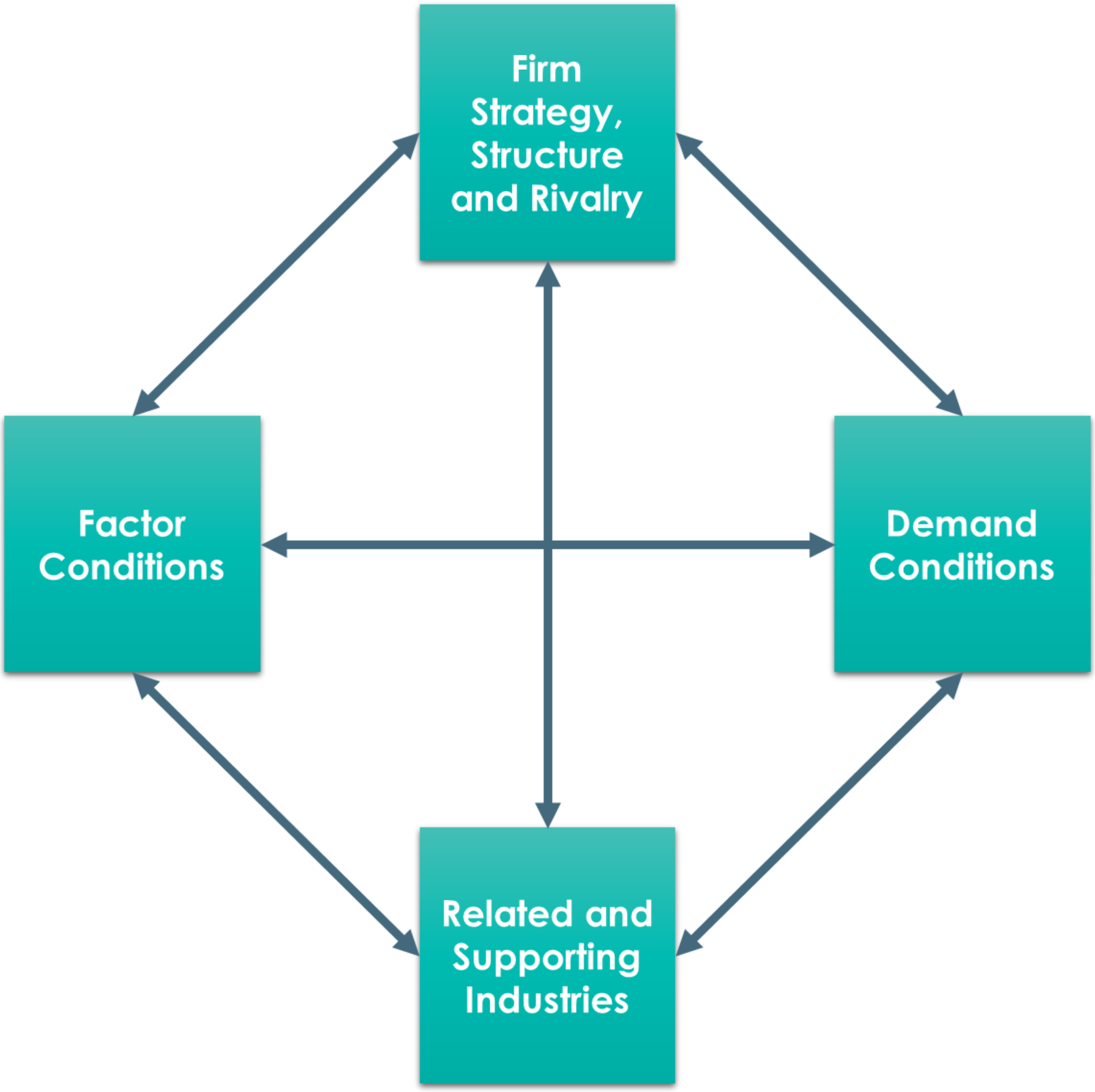
On the other hand, competitive advantage in international markets could be developed in areas where no strong starting conditions exist, albeit more challenging than when these conditions are in place. The ability to innovate, creating better or cheaper products or services than globally established competitors, ultimately shapes the possibility of establishing a competitive advantage (Box 2).

Box 2. The Porter model

The Porter model is often used to help understand the competitive advantage a nation possesses. According to this model, a nation's competitiveness depends on the capacity of its industry to innovate and upgrade, which in turn depends on four conditions known as Porter diamond (see Figure 12):

- Factor conditions, including existing basic and advanced inputs, as well as the ability to further introduce additional advanced inputs where needed. Basic factors, such as natural resources, may create the ground for international competitiveness but can never turn into real value creation without advanced factors. Advanced factors are more sophisticated, such as human resources and research capabilities. These involve sustained and heavy investment and are specialised to an industry's particular needs. Competitive advantage results from the presence of institutions able to create specialised factors and continually work to upgrade them.
- Demand conditions, comprising aspects such as market size, growth and sophistication. These characteristics can help companies create competitive advantage, for instance, when sophisticated domestic demand pressurises companies to innovate faster, creating advanced products earlier than foreign competitors.
- Related and supporting industries shaping cost-effectiveness and, even more importantly, supporting innovation and upgrading, which depends on close working relationships. Quick and constant flow of information between suppliers and end-users, ongoing exchange of ideas and innovations, can accelerate the pace of innovation.
- Firm strategy, structure often shaped by national culture, with no managerial system being universally appropriate to innovate and rival the most critical element to creating pressure to innovate.

Figure 12. Porter's diamond – determinants of national competitive advantage



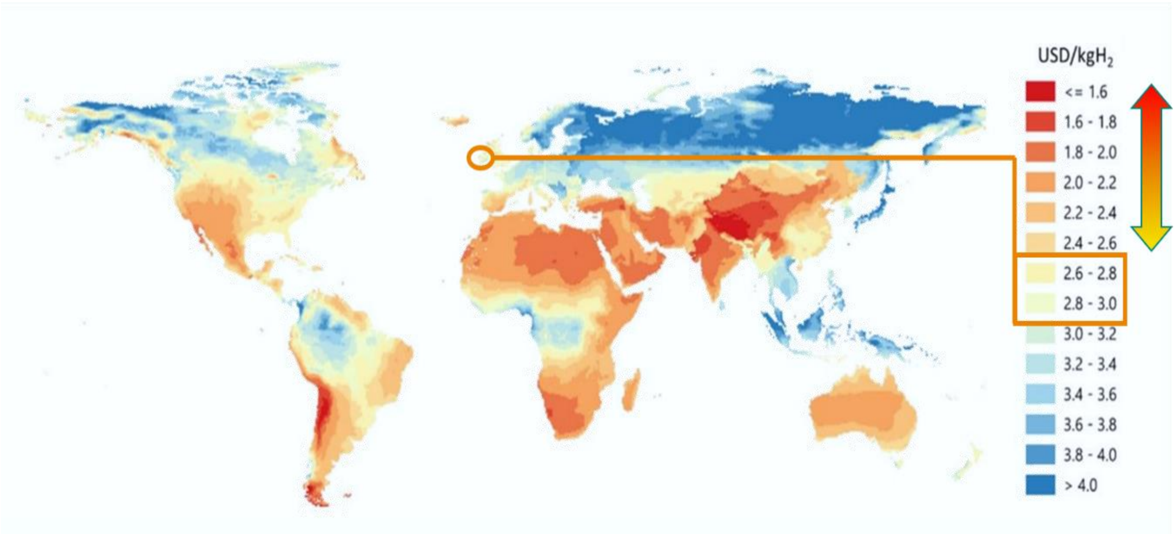
E-fuels for agribusiness

Stakeholders suggested that specialising in synthetic fuels may be useful, given agribusiness' significant contribution to the Northern Irish economy. Their proposals mainly focused on green ammonia and green diesel replacing conventional ammonia and diesel used in fertiliser manufacturing and agricultural machinery, respectively.

In line with the Porter model, domestic demand characteristics steer innovation when creating a need for specialised differentiated products tailored to specific needs. Green ammonia and green diesel are significantly different from conventional ones as they do not have a carbon content. However, green ammonia or green diesel produced in Northern Ireland will not be able to differentiate from the green ammonia or green diesel produced elsewhere in the world – fundamentally, its chemical content will be the same.

Accordingly, achieving international competitive advantage in e-fuel production is dependent on the ability of each country to compete in costs. A critical factor shaping this possibility is green hydrogen competitiveness, as it is the main input for other e-fuels. As Figure 13 shows, Northern Ireland ranks behind various other economies in the cost of hydrogen, reducing its ability to compete in a global market.

Figure 13. Hydrogen costs from hybrid solar PV & onshore wind systems in the long term

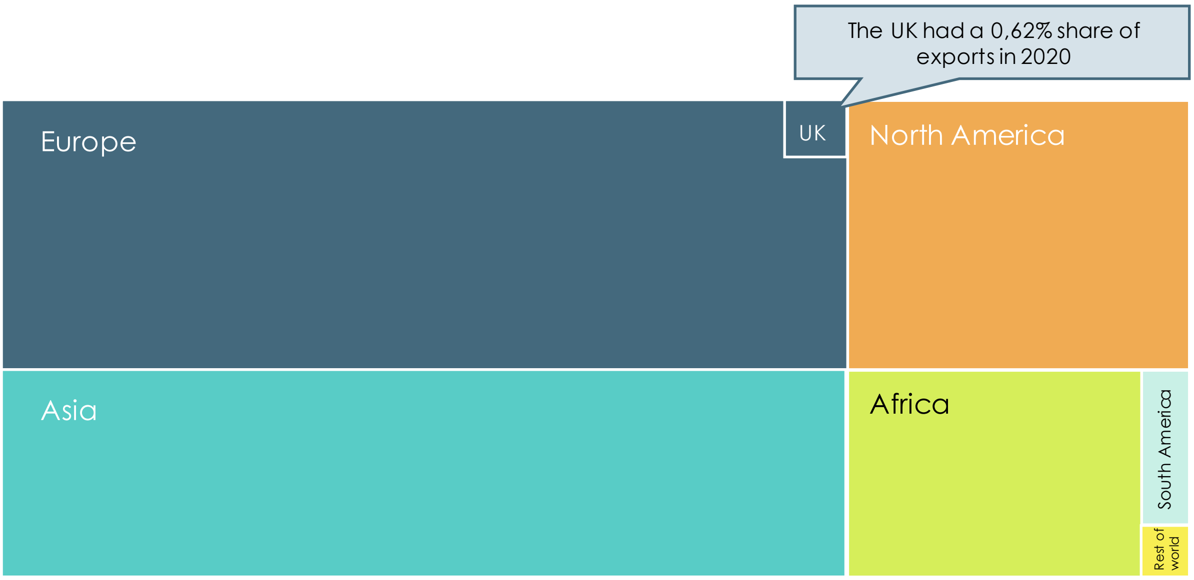


Source: IEA – The Future of Hydrogen

It also appears unlikely that the national agricultural sector or fertiliser manufacturing industry in Northern Ireland could provide the scale to gain cost reductions earlier than other countries. While agribusinesses have a significant contribution to the Northern Irish economy, the sector is small in a global context, with Northern Ireland contributing to 5.5% of the UK agricultural production in terms of the sector's income.[33] The UK also appears to have a small contribution to the global market of fertiliser production (see Figure 14).

[33] Department for Environment, Food and Rural Affairs, Department of Agriculture, Environment and Rural Affairs (Northern Ireland), Welsh Government, Knowledge and Analytical Services, The Scottish Government, Rural and Environment Science and Analytical Services (2020) Agriculture in the United Kingdom 2019.

Figure 14. Exporters of fertilisers in 2020



Source: Observatory Economic Complexity[34]

We therefore recommend caution in adopting policies to leverage the local agribusiness sector to develop these products. Doing so at the expense of cost competitiveness could undermine the affordability for consumers of domestic products and their competitiveness with other economies.

E-fuels for shipping

Stakeholders also suggested harnessing first-mover advantages arising from developing a specialism in the global market for shipping e-fuels. Proposals mainly focussed on the production of green ammonia and green synthetic fuels to replace conventional fuels used in the maritime sector.

Similarly to e-fuels for agribusiness, the absence of carbon in green ammonia and green synthetic fuels makes them significantly different from conventional ones. However, once again, it is not possible to significantly differentiate those produced in Northern Ireland from those produced elsewhere. And for this reason, international competitive advantage arises from each country's ability to compete in costs.

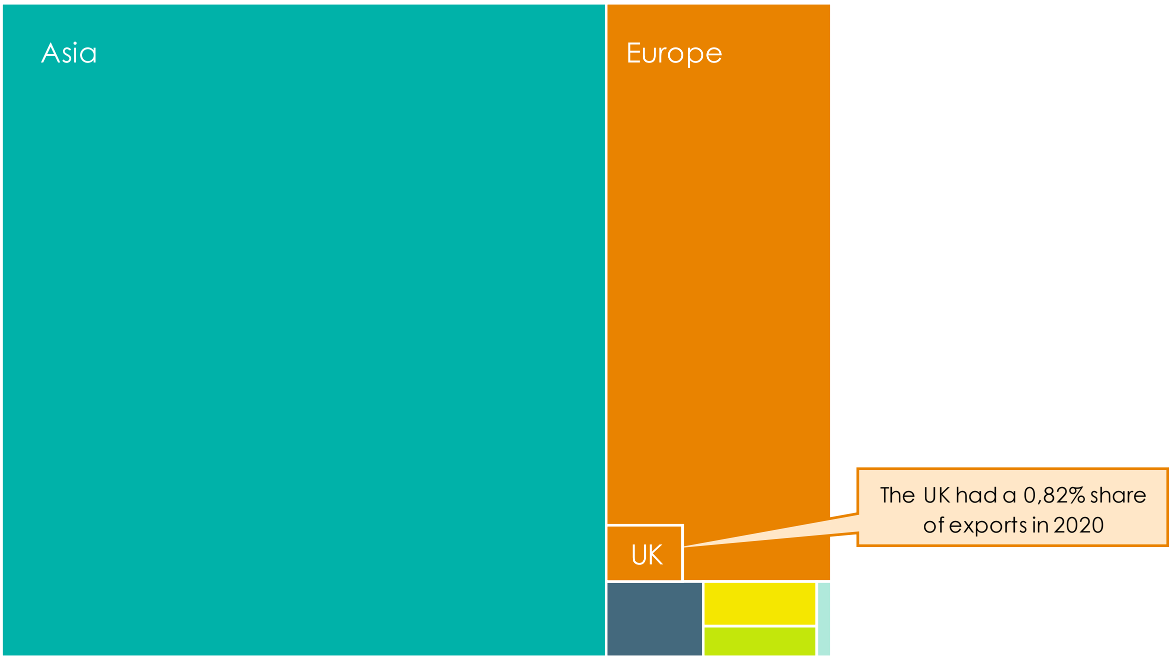
Since green hydrogen is one of the main inputs in the production for e-fuels, its cost is a critical factor for determining Northern Ireland's competitiveness. As noted in Figure 13, Northern Ireland ranks behind various other economies in terms of green hydrogen cost and this reduces the region's ability to compete in a global market.

[34] Observatory of Economic Complexity

It also seems unlikely that the sector in Northern Ireland could provide the scope to gain cost reductions earlier than other countries. In fact, the UK sector is small in a global context (see Figure 15), and Northern Ireland contributes to just 6% of UK port traffic.[35]

For this reason, we would again recommend caution in adopting policies to leverage the local maritime sector to develop these products.

Figure 15. Exporters of passenger and cargo ships in 2020



Source: Observatory Economic Complexity[36]

Technology development

Developing a specialism in technology development for the green hydrogen economy was also suggested by stakeholders. This appears appropriate, considering the proposed assessment criteria.

Northern Ireland has developed innovations in hydrogen production equipment and appliances, most notably dedicated buses, with patents[37] providing evidence of this

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35 Department for Transport (2022). Port and domestic waterborne freight statistics (PORT0101)

36 Observatory of Economic Complexity

37 For instance, Dr Nigel D. L. Williamson, Clean Power Hydrogen Technology Director & Co-founder, holds over 160 patents worldwide for his hydrogen and sealing technology designs. One of these patents is for a membrane-free electrolyser.

contribution.[38] As such, starting conditions appear in place to develop this specialism.

Various factors indicate the possibility of maintaining a competitive advantage in this area. The most important one is the significant demand, with global dimensions, for technologies enabling cost reductions for green hydrogen production, transmission, distribution and end-use. Unlike the production of commodity fuels, where the chemical content is the key attribute, the scope for differentiation in this activity is significant. Technologies proving to enhance cost-efficiency will be able to attract a substantial demand.

Starting conditions also indicate that Northern Ireland may have the skills and information exchanges needed to drive innovation in the hydrogen-related technologies.[39] In this regard, the Hydrogen Training Academy pilot promoted by the Mid & East Antrim Borough Council[40] provides an example of existing communication channels between universities and industry with the purpose of supporting the development of green sectors. The pilot builds from the close interaction between universities and industrial partners via the Manufacturing Taskforce to develop and deliver skills trainings in the hydrogen sector.[41]

This specialism appears in line with the Energy Strategy's focus on creating a green economy, with its corresponding steer of setting up a Hydrogen Catapult accelerating innovation. This specialism could strengthen an exporting-potential activity – technology advancement for a global hydrogen economy – while contributing to local efforts to enable green hydrogen use for decarbonising Northern Ireland's energy consumption.

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[38] BEIS funding awards to Catagen also provide evidence of the region's innovation capabilities. This year, BEIS awarded funding to five of Catagen's hydrogen projects under the following programmes:

- Low Carbon Hydrogen Supply (May 19, 22) for recirculating gas reactor technology for green hydrogen production and liquid hydrogen fuel carriers,
- Red Diesel Replacement competition (May 31, 2022) for a high-pressure hybrid pumping system for hydrogen storage and dispensing, and e-fuel as a drop-in replacement for red diesel.
- BECC innovation programme (August 4, 2022) for the production of biohydrogen from waste biomass

[39] Skills and information exchanges relate to 'factor conditions' and 'related and supporting industries' in Porter diamond's framework.

[40] In partnership with Northern Regional College, Belfast Met, University of Birmingham, Queen's University Belfast and Ulster University and in consortium with industry players such as Wrightbus, Energia, Translink, Firmus, and EP UK Investments.

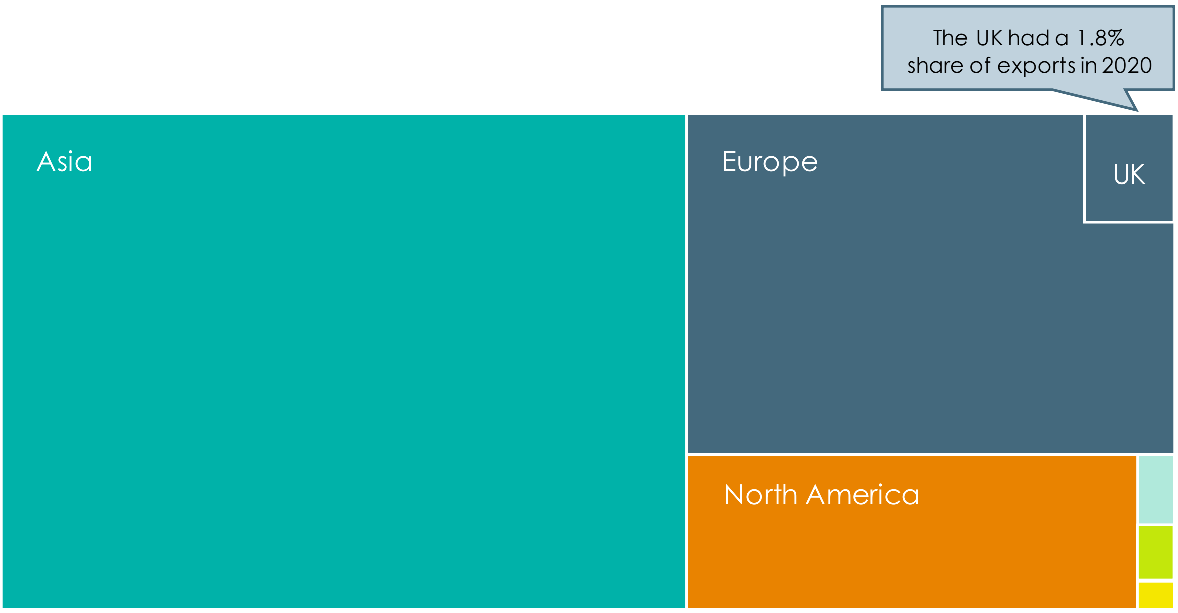
[41] We understand that a set of wider projects, the iLAB skills training workshop and the i4C 'Innovation & Cleantech' Centre will build on the Hydrogen Training Academy experience to continue offering skills trainings and foster collaboration among entities operating in clean technology sectors.

Hydrogen equipment

Finally, stakeholders suggested leveraging technology developing capabilities to establish an additional specialism in technology manufacture. Among technologies, the strongest steer was towards hydrogen production equipment, with a mentioned advantage of contributing to tackling delays in importing this machinery.

The UK Hydrogen Strategy refers to a strong reputation for engineering and manufacturing in Northern Ireland, which could point to favourable starting conditions.[42] However, an examination of top exporters of various machinery (acknowledging it is an imperfect indicator for a specialised type of equipment) suggests the scale does not exist yet (see Figure 16). In addition, potential to develop a global competitive advantage would require tackling skill gaps identified in engineer and manufacturing technologies as presented in the Skills Strategy for Northern Ireland.[43]

Figure 16. Exporters of machinery 2020



Source: Observatory Economic Complexity[44]

Notes: Machinery includes gas turbines, semiconductor devices, low-voltage protection equipment, integrated circuits, gas turbines, machinery having individual functions, together with computers, broadcasting equipment, office machine parts and telephones

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[42] DfE (2021), [Energy Strategy - Path to Net Zero Energy,] *"We have an engineering pedigree, research and skills bade that has matured into a world-leading advanced manufacturing, materials and engineering sector."* (p. 33)

[43] Department for the Economy (2022) [Skills for a 10x Economy – Skills Strategy for Northern Ireland.]

[44] [Observatory of Economic Complexity]

While readily available equipment is necessary to kick-start the sector, we recommend avoiding policies that could lock the industry into equipment that could compromise local green hydrogen production's cost competitiveness and affordability. Significant cost or time reductions in delivery time (possibly years) could justify support for this specialism. Otherwise, if equipment assembly elsewhere (even for technologies developed in Northern Ireland) ensures competitiveness and affordability of domestic production, importing equipment could be more appropriate to ensure green hydrogen supply is fit for purpose.

3.2.2 Developing specialisms in a Green Hydrogen economy: Summary

Developing a green hydrogen economy to support decarbonising ambitions could favour establishing specialisms. Fostering specialisms could expand economic impacts if it does not compromise the original objective - namely, developing green hydrogen as cost effectively as possible and integrating it in the energy matrix to decarbonise energy consumption.

As section 6.1 describes, the major economic contribution that a green hydrogen sector would bring to Northern Ireland is making energy supply clean and reliable. Its contribution to the economy would be the largest if policy direction ensures the sector develops cost-effectively, guaranteeing the country benefits from an affordable and competitive energy supply.

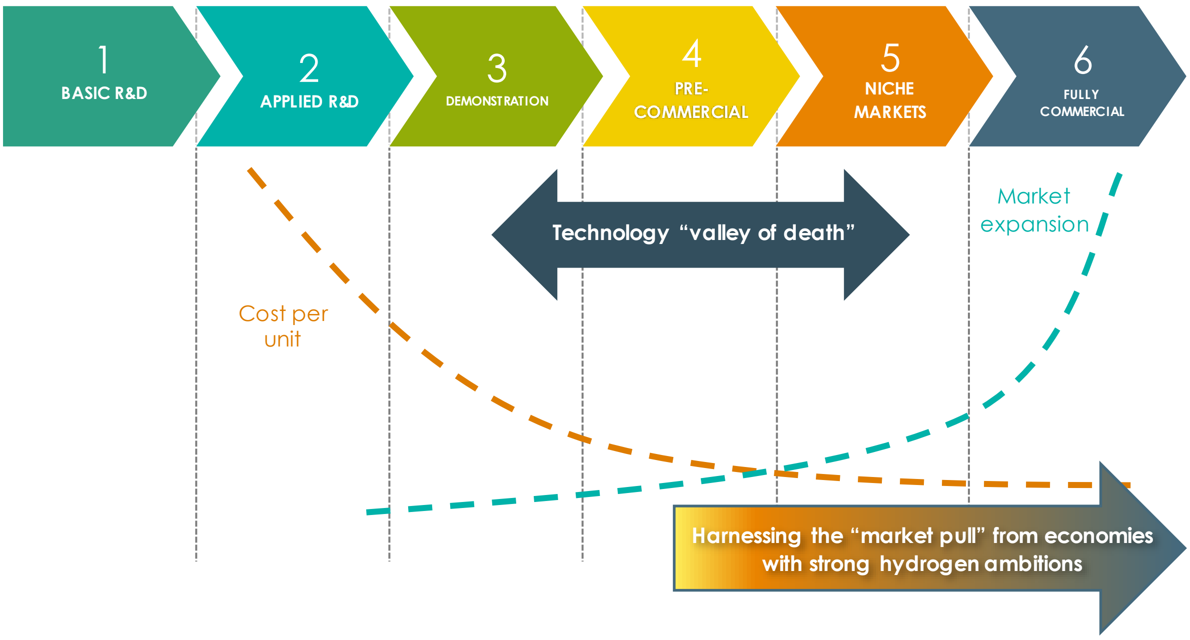
As Figure 17 summarises, our high- level assessment of potential specialisms suggests focusing on technology development for the hydrogen economy, which aligns with the Energy Strategy's focus on developing a green economy, focusing on earlier stages of technology development (see Figure 18).

Figure 17. Summary assessment of specialisms

POTENTIAL SPECIALISM	**Starting point** Linked to existing related business models (considering activities, resources, customer relations, channels)	**Competitive advantage** Potential to compete on **costs** (e.g. by deriving a scale, or exploiting resources) and **quality**
E-FUELS FOR AGRO-BUSINESS	− While agrobusinesses have a significant contribution to the economy, the sector is small in a global context.	? Indications that renewable potentials translate into significantly lower green hydrogen costs in other jurisdictions
E-FUELS FOR SHIPPING	− Northern Ireland does not have a globally leading shipping sector.	? *As above*
TECHNOLOGY DEVELOPMENT	+ Track record of innovations in production equipment and appliances (e.g., hydrogen buses)	+ Scale is less important in this area (hence, Northern Ireland has a good chance to compete)
HYDROGEN EQUIPMENT	+ Strong engineering reputation and manufacturing according to the UK Hydrogen Strategy	? Uncertain – countries with larger production scale (including Germany, Japan, South Korea) may have lower assembling cost.

Source: Frontier Economics

Figure 18. Summary assessment of specialisms



Source: Frontier Economics adapting Grubb M (2004) [45]

[45] Grubb M (2004) Technology Innovation and Climate Change Policy: an overview of issues and options.

Our conclusions should not be read as a recommendation against exploring these suggested specialisms. Instead, it is a recommendation to carefully assess these specialisms before expanding the objectives set for developing the sector.

In summary, we have reviewed the objectives of Northern Ireland in developing a green hydrogen economy. Following our analysis of policy priorities, desk research and stakeholder consultation, we have established the following objectives that the action plan should try and realise:

- Enable green hydrogen to contribute to the decarbonisation of energy supply **(primary)**,
- Develop a specialism in green hydrogen technology development with global market orientation **(subsidiary).**

4 Barriers and enablers to develop a hydrogen economy

We now analyse barriers and enablers to developing a green hydrogen economy in Northern Ireland and realising the objectives set out in Section 3 (enabling green hydrogen to contribute to the decarbonisation of energy supply and developing a specialism in green hydrogen technology development with global market orientation).

We conducted a detailed analysis at the initial stages of the study, which we discussed with stakeholders during our first workshop. We have included the thorough assessment in Annex C. This section focuses on the critical aspects of this analysis, informing priorities for the action plan.

4.1 A long-term vision of the sector

Matrix commissioned this study to take a long-term view of the sector out to 2050. Figure 19 illustrates how conditions are likely to change over time, and what the corresponding policy priorities might be.

Figure 19. A long-term vision of the green hydrogen sector

	NEAR TERM *Horizon 1*	MEDIUM TERM *Horizon 2*	LONG TERM *Horizon 3*
CONDITIONS	• Learning externalities • Niche markets for new vectors • Policy risks across the value chain	• More mature technologies • Liquid markets for new vectors • Greater policy stability across the value chain	• Subsidy free • Stable policy
PRIORITIES	• Delivering initial investments • Getting infrastructure in place to enable market • Delivering learning	• Getting markets to work efficiently • Avoiding cross sectoral distortions	• Internalising carbon externality

Source: Frontier Economics

Note: Labels include a reference to 'horizons'. This is because our analysis follows the Three Horizons Tool from the UK Futures Framework. Strategic considerations shaping opportunities in the short-term – from today to 2030 – correspond to Horizon 1. Those with increased influence in the market towards the mid-term – between 2030 and 2040 – belong to Horizon 2. Factors most relevant to the longer- term impact are allocated to Horizon 3.

In the early stages (roughly out to 2030), getting hydrogen markets up and running is the priority. Strong policy intervention is justified to ensure that investment occurs at socially desirable levels along the value chain and to deliver learning externalities from early investments.

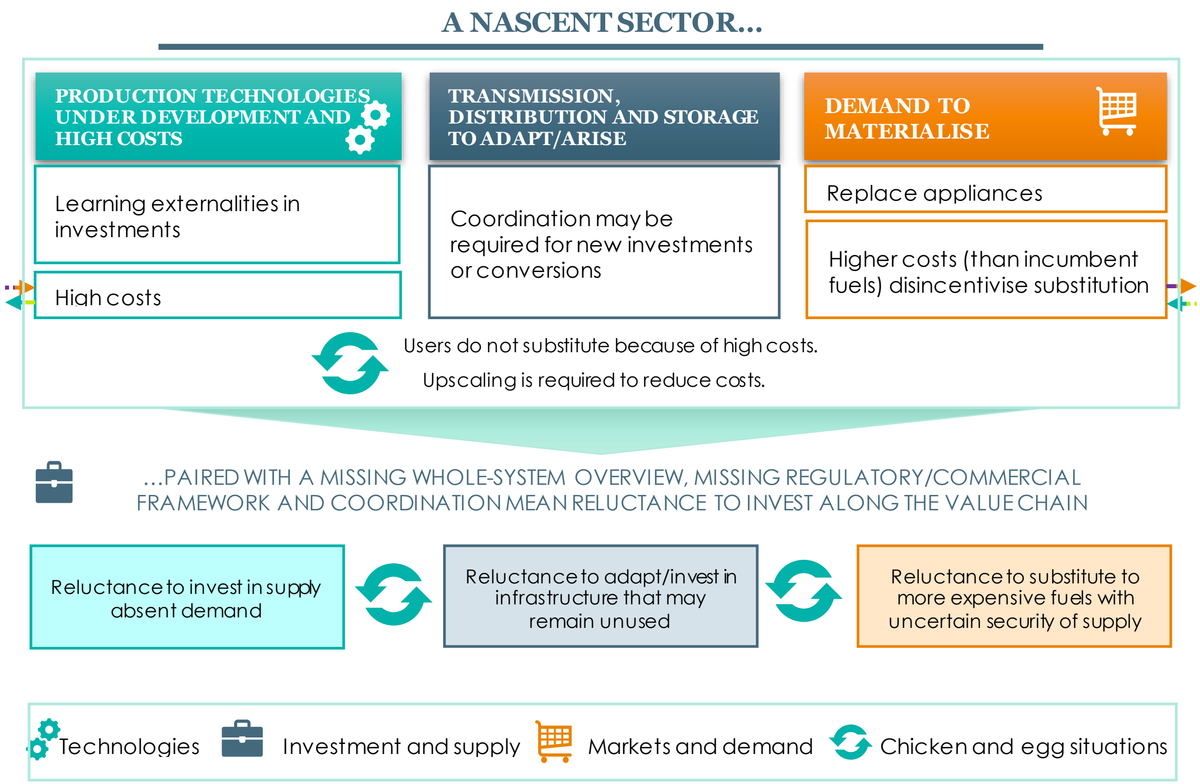
In the medium term (between 2030 and 2040), policy may still be required to support the growth of the sector. However, a greater emphasis should be put on efficiency, to ensure the sector starts transitioning to a merchant state with less public intervention.

In the long-term (between 2040 and 2050), the ambition would be that the sector operates without support, with stable policy driving private investment. The focus of policy here could be purely on internalising the carbon externality (e.g., via a carbon price).

4.2 Deep dive on near term priorities

Tackling investment constraints along the value chain is the near-term priority to kick-start a green hydrogen economy. These investment constraints are inherent to the nascent character of this sector. Some barriers are specific to each stage of the value chain (production, transport and storage, and demand) and others are overarching. This section describes those barriers summarised in Figure 20.

Figure 20. Barriers to investment in the hydrogen economy



Investment barriers specific to production

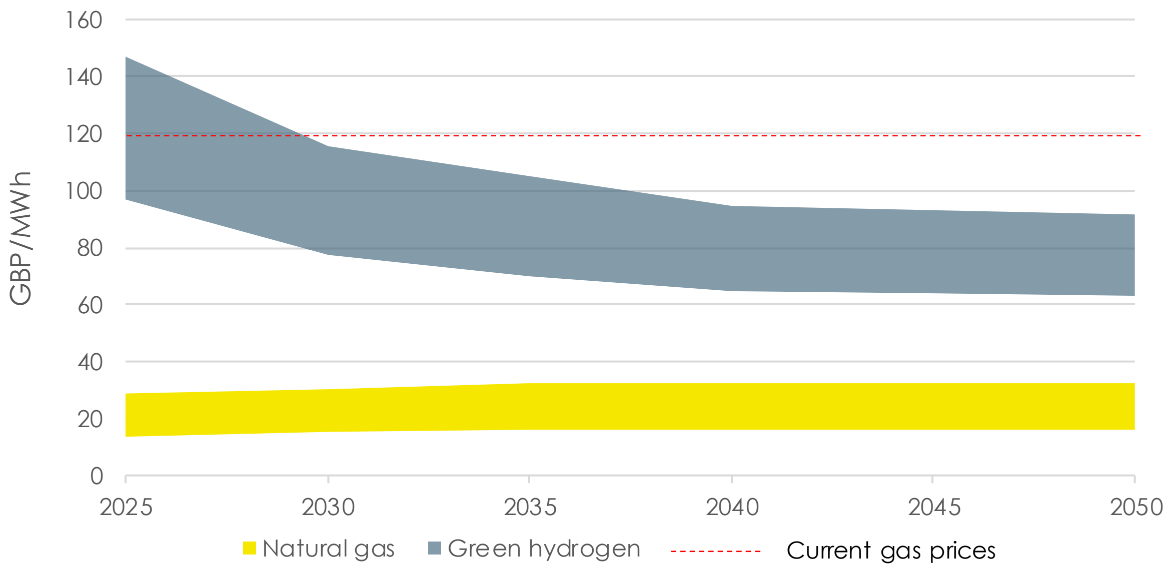
Green hydrogen production technologies are under development, with electrolysis being more mature, albeit at a small commercial scale.[46] Low efficiency is a key challenge, with high energy consumption and low hydrogen yield rates,[47] resulting in approximately 30% energy losses.[48] Accordingly, until recently, hydrogen production was expected to maintain a higher cost than conventional alternatives, most notably natural gas (Figure 21). Whilst the cost gap appears to have significantly reduced and possibly diffused in the current energy crisis, uncertainty about future natural gas prices, and on the future cost-gap remains. In addition to technology advancement, scaling up is necessary to reduce this cost gap. However, given that costs have to fall for greater demand to materialise, this leads to a chicken-and-egg situation.

46 Piebalgs, A.; Jones, C.; Dos Reis, P.C.; Soroush, G.; Glachant, J.M. (2020) Cost effective decarbonisation Study. Florence School of Regulation

47 Lee, B.; Heo, J.; Kim, S.; Sung, C.; Moon, C.; Moon, S.; Lim, H. Economic feasibility studies of high pressure PEM water electrolysis for distributed H2 refueling stations. Energy Convers. Manag. 2018, 162, 139–144.

48 Agora (2018) The Future Cost of Electricity-Based Synthetic Fuels. Page 12.

Figure 21. Hydrogen cost gap with natural gas in Northern Ireland



Source: Frontier economics based on information from BEIS UK estimates[49] and internal calculations of gas interconnection costs for Northern Ireland[50]

Note: Estimates presented in the chart do not reflect the most recent price variations caused by the latest events. The monthly price of gas in March 2022 was £119/MWh (red dashed line in the chart) and forwards for December 2022 are at £101/MWh (source: Bloomberg, accessed March 2022).

Learning externalities are also important. Investment in innovation can create positive spillovers for other investors, which means the social contribution of innovation often exceeds the private benefits that investors can capture. Production projects also encounter decarbonisation externalities, given that carbon pricing is only present in some polluting sectors and carbon prices do not necessarily fully capture carbon's impact. Consequently, the social benefit of green hydrogen innovation and production may also exceed the private profitability of green hydrogen investment. This provides a further barrier to the development of the sector and suggests that public funding will be necessary and economically efficient.

49 Low carbon hydrogen production costs available at: https://www.gov.uk/government/publications/hydrogen-production-costs-2021 For this chart we used a estimates of green hydrogen costs produced with dedicated offshore electricity. We have included central estimates from BEIS as well as estimates under a Technology cost and technical detail sensitivity.

Natural gas price forecasts available at https://www.gov.uk/government/publications/fossil-fuel-price-assumptions-2019

50 Interconnection costs include GB exit charge and commodity charges. Sources: https://www.nationalgrid.com/gas-transmission/document/135736/download and http://gmo-ni.com/assets/documents/GY2021-2022-Postalised-Tariff-Explanatory-Note.pdf

Investment barriers specific to transport and storage

Green hydrogen transmission and distribution alternatives include road transport (also known as virtual) and physical pipeline networks (see Table 2). Uncertainty in supply and demand poses a barrier to investment in these transport arrangements and storage. In turn, uncertainty in transport and storage infrastructure also poses a barrier to supply and demand investments resulting in another chicken-and-egg situation.

These uncertainties may also result in inefficient investment. This can be a particular problem in the case of pipeline network investment. Private network developers may deploy infrastructure in "tranches" and may be reluctant to future proof their networks by building spare capacity, given the uncertainty over future demand and the concern that such capacity will not be utilised and will thereby undermine the profitability of the investment. The impact on society is potentially higher overall costs due to having to "dig twice" rather than investing in larger-scale infrastructure upfront. Since its modern polyethene gas network could require limited adaptation investments to enable green hydrogen transport, concerns about investment barriers and inefficient investment in networks may be limited in Northern Ireland.

Table 2. Hydrogen, local transmission and distribution costs

Alternatives	Max. capacity	Cost £/Kg/100km	Advantage	Disadvantage
Compressed - road	400 Kg/truck	0.08 – 0.80	Small scale deployment	Scale and distance limits, energy inefficiency.
Liquified - road	4000 Kg/truck	0.40 – 1.60	Lager volumes (compared to compressed)	Inefficiency of liquefaction and boil-off product losses.
Pipeline	100 tons	0.24 – 0.40	Large volume and distance range with high efficiency and low running cost.	Relative expensive investment costs and very large amounts of hydrogen delivery to be justified.

Source: Tashie-Lewis, B., & Nnabuife, S. (2021).[51]

Supply and demand location around the existing network and decisions about virtual transport alternatives would determine whether investments in additional network infrastructure are necessary.

[51] Tashie-Lewis, B., & Nnabuife, S. (2021). Hydrogen Production, Distribution, Storage and Power Conversion in a Hydrogen Economy - A Technology Review. **Chemical Engineering Journal Advances**.

Investment barriers specific to demand

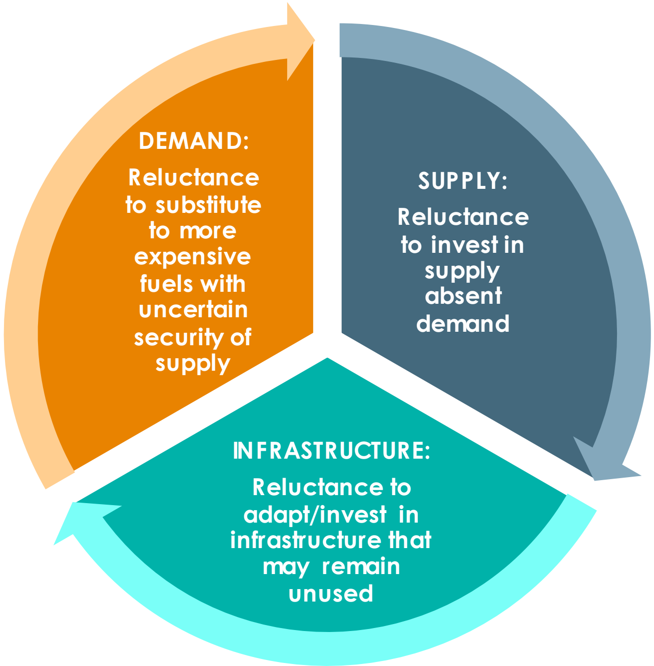
At the level of consumption, investments are also necessary to realise the green hydrogen market potential. The share of conventional hydrogen consumption today, which green hydrogen could directly substitute, is low compared to the potential size of the demand. Most additional demand opportunities require end-users to invest in replacing or adapting their energy appliances. Doing so involves high one-off upfront costs. Given the significant cost gap between green hydrogen and conventional alternatives (see Figure 11 and Figure 22), end-users have limited or no incentives to engage in these investments for appliance substitution or adaptation.

Concerns for the reliability of supply pose further concerns for end-consumers. Expansion of production and infrastructure, especially storage capabilities, would enhance reliability. However, demand materialisation is also necessary for production and infrastructure investments to realise, creating a third chicken-and-egg situation.

Overarching investment barriers

Lack of coordination along the value chain underpins the various chicken-and-egg situations described above and reinforces reluctance to invest along the value chain (see Figure 22). A missing whole-energy-system overview further challenges coordination and impacts investment decisions. Information about potential profitable production and consumption centres is essential for coordination at all stages, including transport and storage infrastructure. Whole-energy-system overview is also a critical basis for whole-system planning ensuring cost-optimisation, as we discuss when proposing action plans (see section 5.1.1).

Figure 22. Reinforcing reluctance to invest along the value chain



Source: Frontier Economics

There may also be barriers created by the current regulatory and commercial framework. Our study identifies the following areas:

- **Renewable electricity availability** faces two challenges: deployment and high prices.
    - Slower deployment creates uncertainty for green hydrogen producers about their projects' feasibility, given the importance of renewable electricity as an input. Various factors might explain slower renewable growth, including lengthy permitting processes, speed of connection to the network and lack of financial support for renewable investments. While hydrogen businesses could potentially alleviate the latter by providing an additional income stream, delays in undertaking renewable investments could further slowdown green hydrogen investments.
    - Costs of electricity supply for production units directly connected to the network could also compromise the economic feasibility of hydrogen production projects. Renewable electricity is the most important cost driver for green hydrogen production.
- **Blending:** As mentioned in Section 3.1.3, blending of hydrogen with methane in existing gas grids is one of the anchors that could help kick-start the sector's

development, by providing a stable source of demand. The current gas regulatory and commercial framework assumes a relatively homogeneous gas quality and therefore is not appropriate for blending. The draft GD23 determination[52] draws attention to this gap, indicating that further work will be required to develop policy, regulation and practical solutions to decarbonise gas networks – including enabling hydrogen injection.

- **Hydrogen network adaptation** and deployment if needed. The regulatory framework should provide clarity about the conditions for network adaptation allowing a dedicated hydrogen transport and implications for network charging. Actors along the value chain would consider costs to inform their investment (including considering alternative transport means). Charging design should balance hydrogen competitiveness/affordability and distributional impacts from cost allocation decisions.
- **Certification** enabling end-users to distinguish green hydrogen from other types (see Figure 3) is missing. Certification is necessary to capture end-users' willingness to pay for the **clean** attributes of green hydrogen, softening the burden of the cost gap with conventional fuels.

4.3 Summary barriers and enablers assessment

Tackling investment barriers along the value chain is the priority to kick-start a green hydrogen economy in Northern Ireland. Reluctance to make the first move before others in the value chain – what we call chicken-and-egg situations – largely justifies the need to support the sector's development. In particular:

- Investment in technology development and upscaling, both necessary to reduce production costs, requires demand to materialise. However, demand would not appear if costs – relative to incumbent fossil fuels – do not fall.
- Uncertainty in production and demand can impede investment in transport and storage. However, producers' uncertainty about their ability to reach demand and consumers' concerns about reliability can hold back investments on both sides of the market.
- Most of the hydrogen demand is likely to come from the substitution away from incumbent fuels, requiring consumers to invest in replacing or adapting their appliances. Consumers may be reluctant to do so, due to concerns about higher costs and uncertainty about reliability. Yet, cost reduction and improved reliability require demand to materialise.

[52] Utility Regulator (2022) GD23 – Gas Distribution Price Control 2021-2018.

Lack of a whole-system overview and a regulatory and commercial framework aligned with the sector's characteristics further prevent investments in the sector. In the following section, we propose an action plan to tackle these chicken-and-egg situations and create favourable conditions for a hydrogen economy to develop in Northern Ireland.

5 Action plan to develop a hydrogen economy in Northern Ireland

This section presents our recommendations for the role of the government in relation to a green hydrogen economy.

As set out in Section 3, the priorities are to:

- Enable green hydrogen to contribute to the decarbonisation of energy supply (primary objective),
- Develop a specialism in green hydrogen technology development with global market orientation (subsidiary objective).

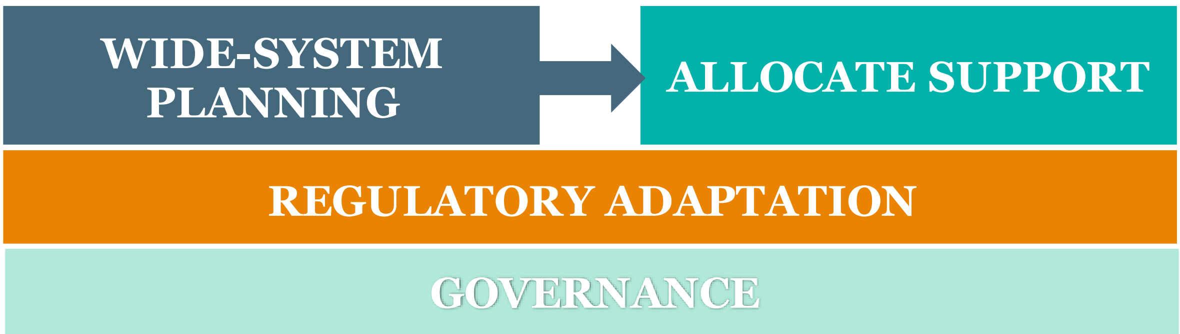
Action needs to adapt to the different circumstances of the market. In the near term, the market is nascent, and priorities are focussed on ensuring it gets up and running. In the mid to long-term, the focus should be guaranteeing that growth keeps momentum, and the sector reaches maturity so that markets can work efficiently.

Our recommendations follow our assessment of Northern Irish objectives in developing a green hydrogen economy and our evaluation of barriers and enablers. Our analysis also builds on a review of international experience, particularly in Portugal, Morocco, Australia and Germany (see Annex D), and discussion with the stakeholders of this study. Our proposals consider differences in needs between the short, medium and long-term as the following sub-sections describe.

5.1 Short-term: Kick-starting the hydrogen economy

Kick starting a green hydrogen economy in Northern Ireland is the near-term priority. We recommend the actions summarised in Figure 23 and described in more detail in the following sub-sections.

Figure 23. Overview of proposed policies to address near term priorities



Source: Frontier Economics

5.1.1 Whole-system planning

As discussed in section 4.1, the nascent character of the green hydrogen sector results in barriers to private investment along the value chain. Reluctance to make the first move before others in the value chain and the corresponding need for coordination between parties can hinder investments.

Reducing these barriers requires providing potential investors with a coordinated perspective on the sector's planned development. The information includes, for instance, a geographic overview of the possible evolution of demand, supply and infrastructure development. This overview reduces uncertainty and also enhances efficiency. One of the concerns for hydrogen network development is that, absent of a long-term perspective, the sector "digs twice" rather than investing in larger-scale infrastructure upfront (described in section 4.2). Planning enables providing accurate perspectives and reduces the risk of confronting this inefficiency.

However, in the context of increased sector coupling (see Figure 24), engaging in stand-alone sector planning does not appear appropriate. International practice is increasingly identifying the need to substitute the traditional method of planning sectors in silos for a coordinated approach, often referred to as whole-system planning.[53] The function could sit in a new entity with the mandate to coordinate with relevant planning bodies in other sectors, as in Great Britain introducing the

[53] Since 2016, the Council of European Energy Regulators (CEER) has advocated that network operators should have a wider vision of the value chain and extend it to other sectors. CEER identifies three layers:

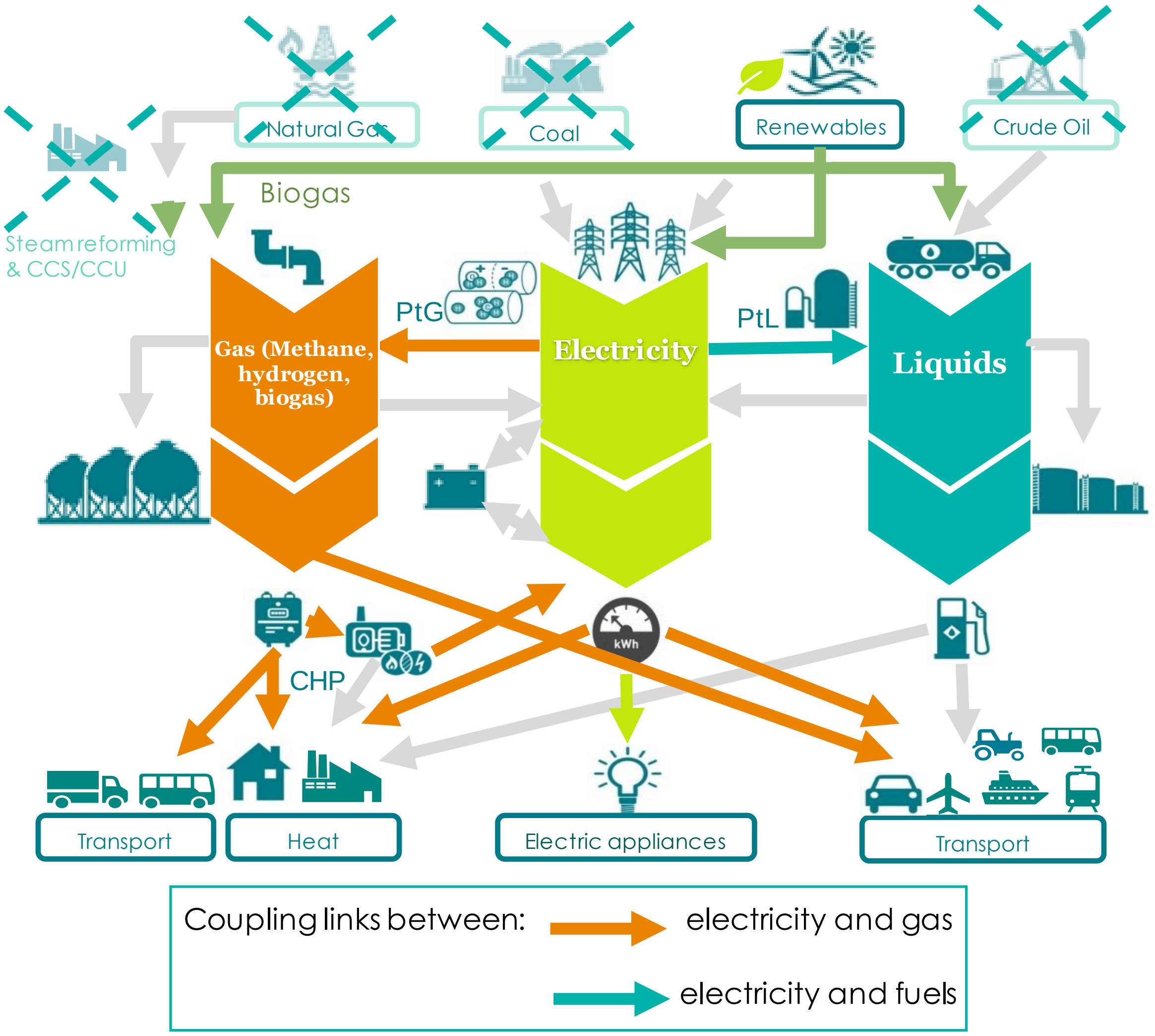
- Whole-network-approach considering TSO-DSO coordination,
- Whole-chain-approach extending considerations to other market players (i.e. generators, storage, end users etc),
- Cross-systems-approach unleashing the flexibility potential in the electricity sector and helping to deploy technologies like power-to-gas plants.

See CEER (June 30, 2020) Paper on Whole System Approaches

The German Energy Agency (Deutsche Energie-Agentur - DENA) explains that joint planning is necessary to reach net zero commitments because the energy transformation extends across all sectors. An upstream system development planning process complements the existing energy infrastructure planning processes with the aim of creating a consistent and coordinated framework. See DENA (January, 2022) Grid Study III - Stakeholder dialogue on the further development of planning procedures for energy infrastructures on the on the way to a climate-neutral energy system.

Future System Operator,[54] or in an existing one.[55] Any entity receiving this mandate should be well-positioned to ensure coordination between sectors and to be accountable for providing appropriate cross-sector planning.

Figure 24. Sector coupling



Source: Frontier Economics and CE Delft (2019) – Potentials of sector coupling for decarbonisation

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[54] The UK government committed on April 6, 2022, to delivering a Future System Operator to look at Great Britain's energy system as a whole, integrating existing networks with emerging technologies, including hydrogen. The Future System Operator will be a new public body funded on the existing capabilities of the Electricity System Operator and, where appropriate, National Grid. It will work with energy suppliers and networks to balance the electricity systems and ensure continued energy resilience and security of supply. See BEIS (April 6, 2022) Government future proofs Britain's energy system with launch of new body to boost energy resilience

[55] Building on existing practices could reduce costs to implement whole-system planning. We understand that Gencomm developed integrated technical and financial simulation models in various jurisdictions, including Northern Ireland, to analyse coupling in the sector.

Whole-system planning comprehensively assesses electricity, gas (natural gas, hydrogen and biogas) and liquid fuels (oil and biofuels) to facilitate judgements on the best balance of energy and to optimise infrastructure, therefore minimising the costs of decarbonisation. In practice, the assessment involves a cost-benefit analysis of carriers and infrastructure alternatives considering all costs and benefits for the society (see examples in Box 3).

Box 3. Example questions for whole-system planning

Whole-system planning involves questions related to energy carrier selection, and therefore the energy mix, and infrastructure optimisation. This box discusses two examples:

1. How do we decarbonise heat in buildings?

The analysis is specific to each jurisdiction. It depends on the possibilities to further reduce consumption via energy efficiency investments, existing heat provision, and additional infrastructure deployment requirements for production and transport (Is district heating available? Is natural gas present? What is its network penetration to sustain a possible expansion of green hydrogen? What are the prospects of the electricity sector? Is it possible to expand its capacity in a sustainable way to meet increased demand?).

Comprehensively considering costs for society requires also assessing implications for end-users, including costs to adjust their appliances and their relative efficiencies. For instance, with less than 100% efficiency, hydrogen boilers are not as efficient as heat pumps which reach more than 200-300% efficiency rates. Yet, heat pumps are more costly and can only operate under specific building conditions, including isolation, which may compromise the cost-effectiveness of direct electrification.

2. How do we optimise power and gas networks to deploy a hydrogen economy?

Jurisdictions where renewable potential is located far from end-users face this question. Competition for scarce space, or community opposition to wind or PV farms may create constraints on the location of renewables. Or there may be significant offshore resources (for example, with increasing prospects of expansion linked to floating technologies).

The questions in this context are:

- **Where to locate hydrogen-producing assets related to renewable sources and end-users?**
- **What are the implications for network infrastructure?**

  Locating hydrogen production units close to renewable sources and far from end-users requires deploying gas transmission infrastructure (depending on distances, virtual transport could be a cost-effective option). The alternative decision would require power network reinforcement or expansion, so that the energy is transported in the form of electricity rather than gas. Costs depend on, for example, the potential of energy transported, distances, and existing infrastructure.

Whole-system planning also enhances possibilities for sector coupling, further providing efficiency. Green hydrogen, for example, could reduce the installed power generation capacity required by providing inter-seasonal flexibility. These services require appropriate long-term and large-scale hydrogen storage and hydrogen turbines. The location of hydrogen turbines relative to storage sites and the power network impact the cost-effectiveness of these inter-seasonal flexibility services. Optimising it requires cross-sector planning that considers the interdependencies between sectors.

5.1.2 Providing public support

Public financial support is necessary to tackle the investment barriers along the green hydrogen value chain discussed in 4.2. Lack of support could not only slow down but also compromise the sector's development. While BEIS undertook UK-wide consultation on business models (summarised in Box 4), the exact form of the support is unknown, and its application to Northern Ireland is uncertain. Two factors may be particularly important for Northern Ireland:

- The choice of the reference price (at present, this is based around the natural gas price and the achieved sales price for hydrogen). Where the incumbent fuel is different in Northern Ireland (e.g., in the transport sector), this may create additional complexity.
- Very small projects (below 5 MW) will be unable to receive grant funding. Stakeholder engagement suggested various projects would be very small in Northern Ireland, creating a need to address this gap.

We also note that the indexation methodology for the strike price will be critical; BEIS is still defining this aspect.

Box 4. BEIS low-carbon hydrogen support proposal[56]

BEIS proposes two alternatives to support low-carbon hydrogen in the UK: a main revenue support mechanism and capital funding. Providing more limited support, applying to the latter is simpler. Capital support is mainly tailored to smaller projects. The following are the salient characteristics of each alternative.

Hydrogen Business Model providing revenue support

Support will apply to green and blue hydrogen. There may be different allocation processes for each technology, and some features may differ (e.g., strike price indexation, as noted below).

The contract will be between 10-15 years.

Support takes the form of a variable premium payment that tops revenue per unit sold up to a strike price. The premium is the difference between a 'strike price' (minimum revenue per unit enabling producers to cover costs) and a 'reference price' (meant to represent the price received by the producer) for each unit of hydrogen sold (see Figure 25).

The reference price for determining the premium or top-up received will be the higher between the natural gas price and the achieved sales price for hydrogen. This design incentivises hydrogen producers to negotiate higher sales prices: observed revenues per unit of hydrogen sold (sales plus subsidy) will be lower if sales prices are below the natural gas price.

The strike price will be indexed to cover uncontrollable levels of cost. Indexation may differ by hydrogen production technologies. See Figure below.

Support will adapt via a 'sliding scale' managing volume risk. Low offtake volumes obtain a higher level of price support. The level of price support falls as volumes increase. The business model can cover production and some associated small scale hydrogen transport and storage.

[56] BEIS (2022), Government response to the consultation on a Low Carbon Hydrogen Business Model

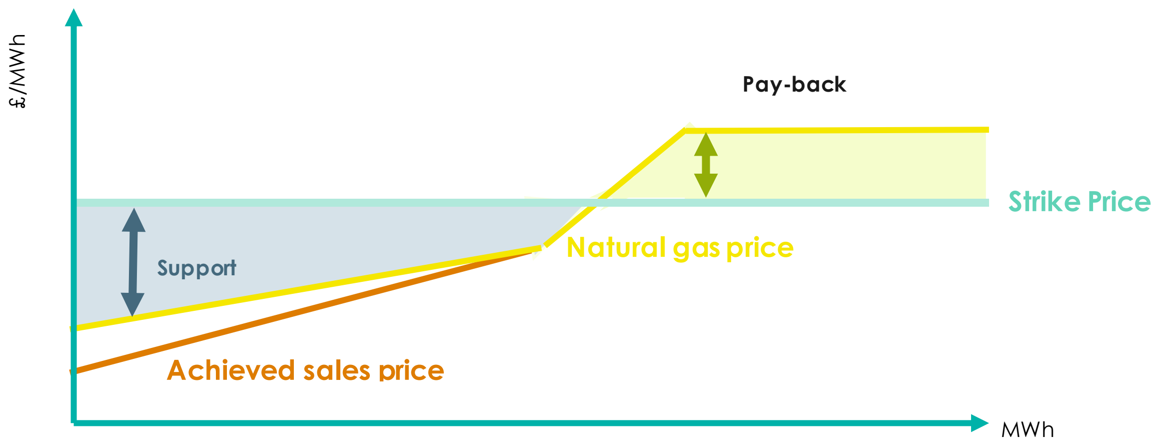
While hydrogen exports would be permitted for projects benefiting from business model support, the specific volumes exported would not be eligible for support payments.

Support will initially be allocated through bilateral negotiation, moving to a more competitive process further down the line.

Net Zero Hydrogen Fund providing capital funding

£240m grant funding is available to support the capital costs of developing and building low-carbon hydrogen production projects. The proposed eligibility criteria include a minimum production capacity of 5MW.

Figure 25. Variable payment design (assuming achieved sales price below natural gas price)



Source: Frontier Economics

Note: For illustration purposes, the chart assumes achieved sales prices are below natural gas prices for smaller sales volumes

It is unclear whether Northern Ireland will adhere to BEIS proposed support. Providing timely clarity about support mechanisms applying in Northern Ireland appears critical to instil investors' confidence and accelerate the sector's development.

Note that BEIS' proposal entails bilateral negotiation for support allocation. If Northern Ireland adopts a tailored process to allocate support, we recommend favouring coordination by prioritising:

Areas identified as potential "supply/demand clusters" in a whole-system planning process.

Projects involving various parts of the value chain, especially when various stakeholders engage into collaboration.

Support to close the cost gap between conventional fuels and green hydrogen, should be complemented with support for reducing switching costs for demand. These costs relate to appliance adaptation and new kit that is required for users of hydrogen, including in the mobility sector. BEIS has currently introduced a number of demand-side schemes (see Figure 26). However, funding for these is limited and focuses on industry (except for the second scheme), reducing its relevance to Northern Ireland. We recommend assessing implementation of complementary subsidies for demand, focused on the mobility sector in Northern Ireland.

Figure 26. Demand side support schemes

Industrial energy transformation fund (Phase 2)	▪ Aims to de-risk key technologies including hydrogen fuel switching by providing support for feasibility and engineering studies, and capital support for first movers to upgrade their industrial equipment. ▪ It will increase readiness for the hydrogen economy by building demand for hydrogen in industry and helping to develop the commercial case for low carbon hydrogen projects
Red diesel replacement competition	▪ Aims to support the development and demonstration of innovative technologies that enable Non-Road Mobile Machinery (NRMM) used for quarrying, mining, and construction to switch from red diesel to hydrogen or other low carbon fuels.
Industrial fuel switching 2 competition	▪ Aims to develop and demonstrate innovative solutions for industry to switch to low carbon fuels such as hydrogen. ▪ The latest round of funding was awarded in winter 2019, with four projects moving from feasibility studies to demonstration.

Source: Frontier Economics

5.1.3 Regulatory assessment and potential adaptation

We have identified the following areas requiring regulatory assessment and potential adaptation to foster the sector's development:

- enabling blending;
- preparing network adaptation or roll-out;
- gas certification; and
- renewable electricity production.

We describe the recommended regulatory assessment and potential adaptation in the following sub-sections.

Enabling blending

As discussed in Section 3.1.3, blending is one of the anchors to develop a green hydrogen economy in Northern Ireland. Making it possible appears critical to kick-start the sector.

The current commercial and regulatory framework for gas assumes a relatively homogeneous quality, which may not be compatible with blending. The main aspects to consider when evaluating the framework include:[57]

- managing the blend and gas quality, ensuring that hydrogen blend is kept within the blend limit,
- defining clear health and safety standards for blending,
- establishing an appropriate allocation of network capacity to hydrogen producers,
- managing specific requirements of certain user types (from those who cannot take any hydrogen to those that could take up to 100%),
- ensuring that distribution and transmission charges facilitate competition in a hydrogen blended system (with potentially increased injections at the distribution level), and
- adjusting billing to final customers to reflect different calorific values at different points of the grid.

The draft GD23 determination draws attention to the gap in the regulatory framework. It indicates further work will be required to develop policy, regulation and practical solutions to decarbonise gas networks – including enabling hydrogen injection. Noting other stakeholders in the UK have engaged in assessing how to adapt commercial and regulatory frameworks, we recommend Northern Ireland to engage in this UK-wide assessment.

[57] Frontier Economics (September, 2020) Hydrogen Blending and the Gas Commercial Framework. Report on conclusions of a NIA study for Cadent.

Network adaptation/roll-out[58]

As discussed in section 3.1.3, the anchor sectors to develop green hydrogen in Northern Ireland are likely to be mobility and blending. We have just discussed the latter in our previous sub-section. Meeting mobility demand could entail virtual green hydrogen transport or investments in production and transport assets, linking specific production sites with specific customers.

Priorities for regulation would include:

- Provisions for **third party access** under non-discriminatory conditions. Since the costs of early investments, most notably in production, are likely to be at least partly funded by government support, third party access terms could be inserted in any early production/consumption subsidy contracts.
- Mechanisms for **sharing third party access revenues** to avoid windfall profits for early support contracts to vertically integrated projects.[59]

Gas certification

Certification is necessary to enable end-users' willingness to pay for *clean* hydrogen to reduce the impact of the cost gap between green hydrogen and conventional alternatives.

BEIS has designed a Carbon Hydrogen Standard for the UK[60] to inform support allocation via the Hydrogen Business Model and Net Zero Hydrogen Fund described in Box 4. In line with the Energy Security Strategy, BEIS will set up a hydrogen certification scheme by 2025, building on this standard. BEIS expects potential updates to the standard in 2023 would follow the 2022 allocation rounds.

The standard will establish a maximum threshold for greenhouse gas emissions in the hydrogen production process to be considered low-carbon. A single label identifying 'low-carbon hydrogen' will apply.

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58 Frontier Economics (2021) Gas network regulation for the net zero transition – study for Catapult Energy Systems.

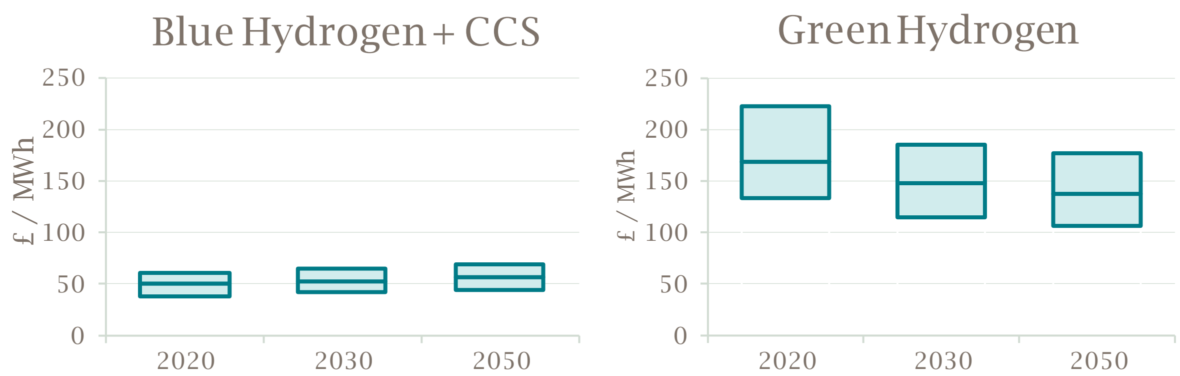
59 We recommend implementing these mechanisms instead of implementing clauses to subtract third-party access revenue streams from revenues. In those cases, investors may discount future revenue streams from third party access and price them into their requests for support, such that these clauses remain of little use.

60 BEIS (April, 2022) The UK Low Carbon Hydrogen Standard – Government response to consultation.

BEIS response to consultation indicates some stakeholders showed concern about a single label adoption.[61] They consider one label for all carbon hydrogen production methods capable of meeting the standard to being fair and simple.[62] They indicate that when developing the standard into a certification scheme further down the line, additional information to customers would be considered, for instance, electrolytic hydrogen meeting the Renewable Transport Fuel Obligation (RTFO) requirements.[63]

Lack of differentiation between production methods would undermine green hydrogen competitiveness. As Figure 27 shows, green hydrogen may almost triple blue hydrogen costs. However, this comparison does not consider the impact on the current energy prices, and there is significant uncertainty about future cost developments. If the crisis does not result in permanent gas price increases, the gap would be expected to close out to 2050 (see Figure 27). However, green hydrogen is preferable to blue from an emissions perspective, as the latter entails relatively significant residual carbon emissions over its lifecycle.[64] .

Figure 27. Low-carbon hydrogen production costs



Source: Frontier Economics based on information from BEIS UK estimates.[65]

Note: these estimates are based on the published BEIS fossil fuel price scenarios, have not been updated to take into account recent rises in the natural gas price. Sustained increases in natural gas prices would affect the cost of blue hydrogen.

[61] Ibid. Page 26

[62] Ibid.

[63] The Renewable Transport Fuel Obligation Order regulates renewable fuels used for transport: See https://www.gov.uk/guidance/renewable-transport-fuels-obligation

[64] Committee on Climate Change (2018) *Hydrogen in a low-carbon economy*. Table 3.1. Available at https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/

[65] Hydrogen production costs available at: https://www.gov.uk/government/publications/hydrogen-production-costs-2021

The chart represents Industrial LRVC for green hydrogen produced using grid electricity and Industrial LRVC for SMR with CCUS produced in sites with 300MW or 1000MV. We have included central estimates from BEIS as well as estimates under a fuel and electricity price sensitivity.

As public financial support for low-carbon hydrogen reduces and decarbonisation efforts strengthen, ensuring differentiation between low-carbon hydrogen types via certification, is likely to be critical to ensure that the emissions impacts of different production technologies are accounted for. The impact in Northern Ireland could be delaying the establishment of the green hydrogen production foreseen in its vision (see section 3.1.3).

Renewable electricity production

As discussed in section 4.2, somewhat stalled wind deployment paired with high electricity prices may constitute an additional barrier to the sector's development. Indications of a strong pipeline of incoming projects, with networks receiving various connection requests, suggest that this concern may not constitute a barrier in the near term. However, considering the time to build and commission renewable assets, it appears relevant to revitalise renewable expansion.

Various factors could explain renewable expansion slow down:

- investors' uncertainty about projects' profitability,
- difficulties to connect to the grid, and
- time lags on permitting.

Northern Ireland does not provide support to new renewable investments today. Lack of support may reduce investors' confidence in entering the market. In providing an additional revenue stream, developing a green hydrogen sector could reduce investors' concerns. In contrast to the European Union, the UK does not plan to adopt an additionality requirement – including renewables not having received support – for hydrogen produced with electricity to count as low-carbon hydrogen. Therefore, support appears necessary for Northern Ireland hydrogen production to remain competitive with other hydrogen produced using electricity in the UK.[66]

Difficulties in connecting renewable energy sources to the grid could also slow down the development of a green hydrogen sector. While hydrogen production could be an alternative for renewable electricity – curtailed or otherwise – network constraints could limit the connection of hydrogen-producing equipment and the possibilities to optimise their location. A market review appears necessary to explore whether these issues are in place in Northern Ireland to adjust regulation and policy accordingly.

Time lags for obtaining permits would also constitute a barrier to renewable deployment that hydrogen production cannot solve. This issue could translate into

[66] BEIS (April 2022) The UK Low Carbon Hydrogen Standard.

delays in establishing and expanding a green hydrogen-producing sector. Regulatory adaptation is the primary mechanism to tackle this issue. We recommend exploring whether this path is necessary for Northern Ireland.

5.1.4 Developing a Hydrogen Governance body

To support the development of the hydrogen sector in Northern Ireland we suggest creating a Hydrogen Governance function. This would be an entity (either a new entity or a function within an existing entity) where relevant stakeholders in the hydrogen economy can join forces to guide the actions needed to ensure the growth of the sector. The governance structure would ideally articulate a hydrogen strategy which sets out objectives, milestones and action plans favouring continuity in policies and attributing responsibilities to each entity involved in developing the sector. We envisage that both stakeholders from the public and private sphere could be part of this.

The main stakeholders comprising the governance body should be all the relevant entities directly involved in the development of the sector. As we mentioned in section 4.2, the hydrogen sector in Northern Ireland is still at a nascent stage. For this reason, kick-starting it will require policy interventions along the value chain (especially in the near term). It is important that the bodies in charge of doing so will reflect the market's needs and coordinate among each other.

To make sure that coordination and communication are in place we recommend that the Governance Body include the Departments of Northern Ireland's Executive whose sectors are expected to be affected by hydrogen. For example, we envisage that at least the Department for the Economy, the Department of Agriculture, Environment and Rural Affairs, Department for Infrastructure and the Department of Education could be part of the Governance Body.

The body could also enable communication between the relevant departments and the relevant representatives of the industry and those entities promoting the development of the hydrogen sector. We envisage that relevant private and public stakeholders of the industry also take part in this body with a role of "consultation".

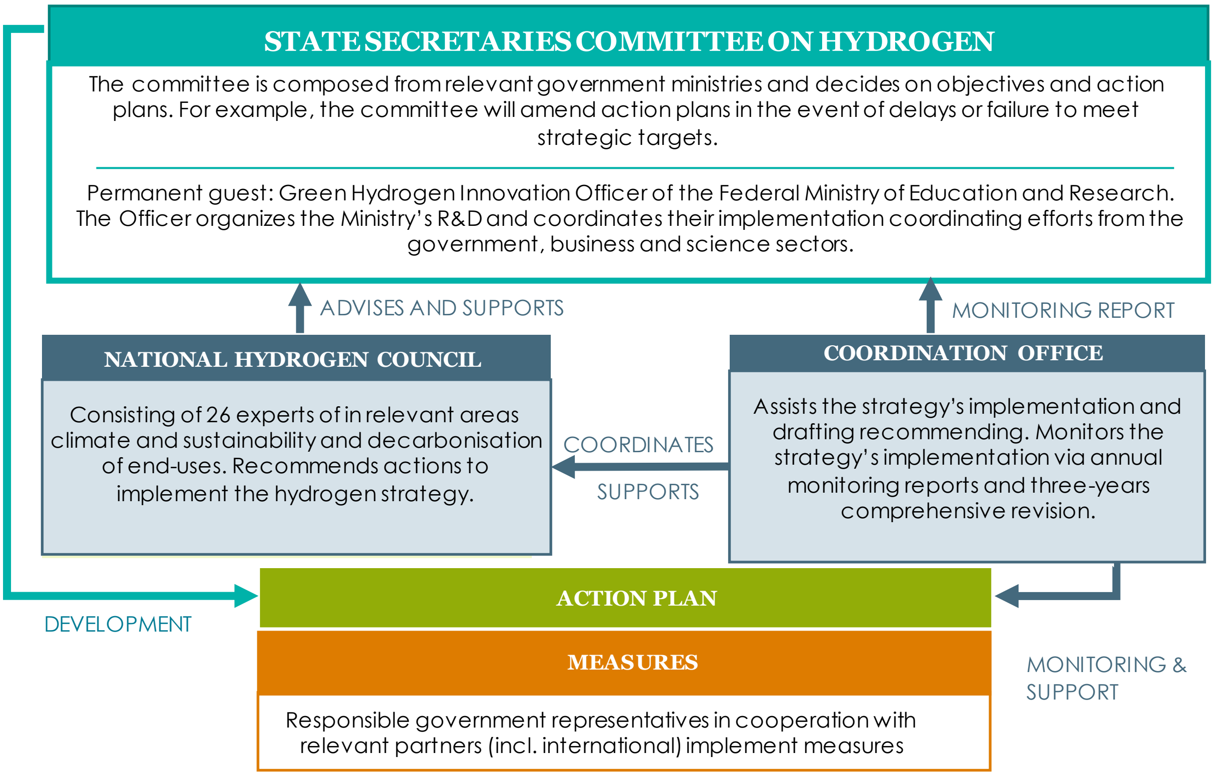
Where possible, they would provide early advice and feedback on policy interventions and discuss potential adjustments. These could be actors that operate along the hydrogen value chain such as key representative of producers and large consumers. Based on our engagement in Northern Ireland we also suggest that participation should also be allowed to involve public entities like boroughs and councils driving initiatives related to hydrogen.

In this way the Governance Body would not only act as a direct point of contact between policy makers and the industry, but it would also act as a forum for discussion among representatives along the value chain (from production to end-users, sustainability and climate experts). Moreover, this would allow the body to receive information useful to monitor the sector's development and consequently formulate and adapt its action plans.

The body should also have a function dedicated to monitoring the development of the sector and the implementation of its action plans. As discussed at the beginning of section 4, the market will evolve and with this so will the sector's policy needs. For this reason, it is important to set in place a function that will monitor the sector development. This will ensure that timely adjustments to policy takes place, for instance, resolving bottlenecks preventing the effective implementation of the action plan. Monitoring the market will also ensure policy adaptation to the needs arising at each stage of the sector evolution and revise priorities in case the sector development requires so.

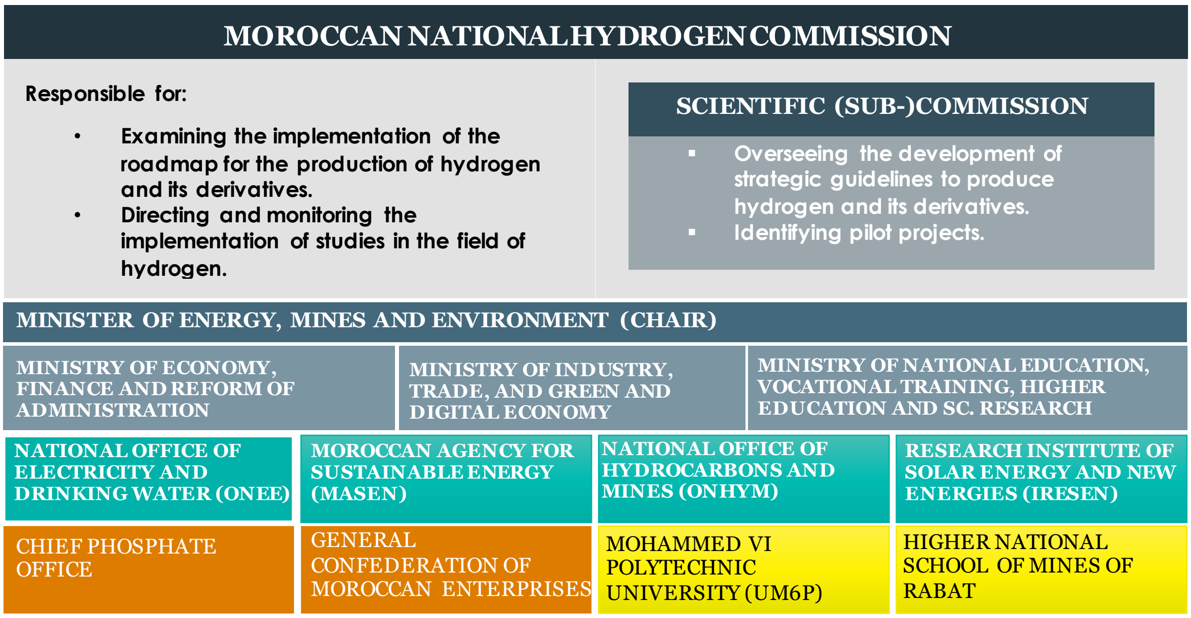
Germany and Morocco both rely on a Hydrogen Governance Body to develop their sectors. Figures 28 & 29 show the structure of Germany and Morocco's governance bodies. In both cases communication between ministries and relevant stakeholders is in place. In Morocco this is done through the scientific sub-commission, in Germany it is through the National Hydrogen Council. Moreover, in Germany the coordination office has the role of monitoring the sector development and ensuring planned actions adjust accordingly.

Figure 28. Governance structure for hydrogen in Germany



Source: Germany's National Hydrogen Strategy[67]

Figure 29. Governance structure for hydrogen in Morocco



[67] Germany's Hydrogen Strategy

5.2 Short-term: Enhancing technology development

Ensuring that Northern Ireland participates in a global hydrogen economy with technology development is part of the objective underlying the development of a hydrogen sector in Northern Ireland. Developing a specialism in technology development has the potential to create a profitable economic activity and, more generally, could contribute to further developing green hydrogen technologies which is key to speeding up its integration in the energy mix.[68]

This objective is in line with the Energy Strategy's goal to develop a green economy in Northern Ireland by creating a hydrogen centre of excellence in research and innovation. To ensure this, the Energy Strategy identifies establishing a Hydrogen Catapult as one of its key priorities.

> *In order to take advantage of the unique hydrogen opportunities available to Northern Ireland we will implement a Hydrogen Catapult in partnership with academia. This centre of excellence in research and innovation will bring together key players across the hydrogen economy.*[69]

Developing this specialism requires demand for this service, creating a business case for it, and favourable pre-conditions to build on. As we will shortly describe, these are all in place. Accordingly, establishing a Hydrogen Catapult – i.e. a centre with R&D infrastructures where businesses and research and academic communities can collaborate to adopt, develop and exploit their innovation – appears an appropriate strategy to favour technology development.

Strong global low-carbon hydrogen ambitions (see Figure 30) mean that demand to further develop hydrogen technologies is in place. Northern Ireland's aim to develop the sector internally reinforces this demand domestically and provides opportunities to test development.

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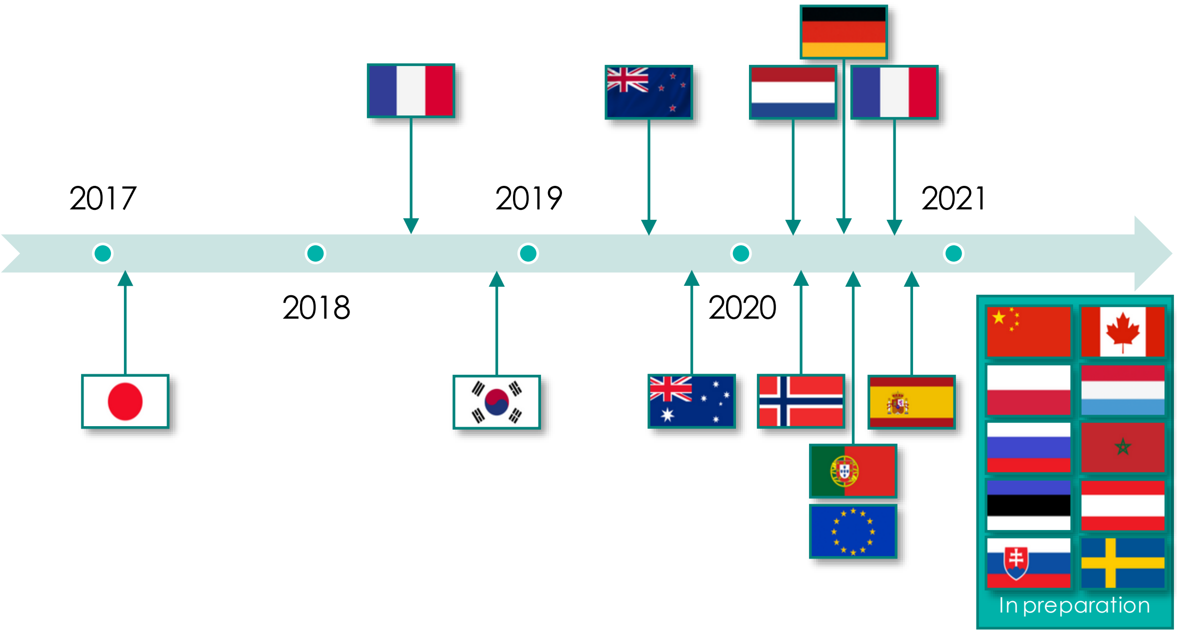
[68] As noted in section 4.2, at the moment green hydrogen technology still needs to develop to drive down costs and kickstart the economy.

[69] DfE (2021), *Energy Strategy - Path to Net Zero Energy.*

Figure 30. Hydrogen strategies published out to 2021 across the world



Source: Kantor (2021)[70]

Favourable pre-conditions are also in place. Stakeholders underlined that Northern Ireland has a track record of patented technologies in production of hydrogen equipment and appliances.[71] Synergies are also in place, with fluent communication and partnerships between research institutions and businesses.

The Hydrogen Catapult further institutionalises and enhances existing communication channels, speeding up innovation.

As mentioned above, various economies with hydrogen ambitions are equally involved in further developing hydrogen technologies. Establishing the Catapult at early stages appears relevant to ensure that Northern Ireland can compete in the race for developing these technologies.

AMIC[72] is conducting a study to explore ways to develop the Hydrogen Catapult. In particular, the study evaluates the market needs and technology readiness for hydrogen and then explores various models and delivery vehicles for the creation of a Hydrogen Catapult.

[70] Kantor (2021) Possible regulation of hydrogen networks. Study for the European Union Agency for the Cooperation of Energy Regulators (ACER)

[71] For example, Wrightbus is a Ballymena-based bus manufacturer manufacturing hydrogen-fuel buses.

[72] In partnership with Queen's University Belfast, Catalyst and EY.

We suggest that, once in place, the Hydrogen Catapult sits in the Hydrogen Governance Body (discussed in section 5.1.4) as part of the consultation body.

5.3 Medium term

In the medium term, technologies will be more mature, and the sector will be growing. We identify three potential actions to ensure sustained growth while paving the way towards a well-functioning competitive market with competition between energy carriers.

In this context, we recommend the following actions, described in this sub-section:

- Harnessing storage potential,
- Growth enhancing measures,
- Regulatory adaptation for networks.

Harnessing the storage potential

Northern Ireland appears to have a strong large scale seasonal storage potential at Islandmagee near Larne. The site is capable of storing approximately 1,173 GWh and of delivering 61 GWh/day of hydrogen.[73]

Harnessing this seasonal storage potential is not necessary to kick-start the sector. However, once the sector is growing, seasonal storage may further optimise Northern Irish clean energy supply by reducing the required renewable installed capacity to produce green electricity and possibly green hydrogen. Green hydrogen large-scale storage could also help enhance the security of its supply and clean electricity.

It is the role of whole-system planning to determine the net social benefit of harnessing this potential. Alternatives may be specific to the green hydrogen sector or may extend to the power sector, creating new demand for hydrogen. Costs to retrofit existing gas plants or deploying new hydrogen ready ones would be part of the social costs to consider when assessing the net benefit of harnessing hydrogen storage potentials to provide inter-seasonal flexibility to the power sector.

[73] ENTSOG (2020) Ten year development plan (p. 768), The ENTSOG study presents an estimated working volume 420mcm. We have converted this to GWh by assuming the 420mcm refers to standard cubic meters of gas (1atm, temperature of 15O°C) Frontier Economics (June 2021) Hydrogen Options for Northern Ireland. A report for Northern Ireland Electricity.

If net social benefits are positive, making use of this potential could also translate into improving green hydrogen reliability. Doing so has the potential to attract further demand reinforcing growth in end-use sectors.

Growth enhancing measures

Once the market has been established and technologies mature, it could be possible to set quotas, which parties subject to them can realistically meet, to promote further growth. At earlier stages, implementing this type of measure could damage the efficiency of energy supply, exposing market participants to risks and costs they cannot fully control.

Opting for these additional measures requires careful assessment of policies in other countries, most notably in jurisdictions competing with Northern Irish firms for exports or domestic demand segments. If these jurisdictions do not implement equivalent measures, doing so in Northern Ireland would expose local firms to higher costs potentially damaging the competitiveness of the Northern Irish economy.

Regulatory adaptation[74]

Demand for green hydrogen for heating largely shapes whether network requirements change in the medium to long term compared to the initial market stages. As discussed in section 3.1.3, the role of hydrogen to decarbonise heat in Northern Ireland is uncertain in the middle to long term. Accordingly:

- If whole-system planning found green hydrogen integration the cost-efficient decarbonisation alternative for Northern Irish buildings, network expansion could be necessary. This is because of the limited reach and penetration of the existing network.
- If direct electrification showed the largest net social benefits, blending in existing gas networks would be discontinued. Hydrogen demand in mobility and industrial uses would remain structured in clusters around hydrogen networks deployed at initial market stages.
- Regulatory requirements depend on each situation. Hydrogen integration in heat would require more extensive regulation of assets in line with current regulation of the gas network.

[74] Frontier Economics (2021) Gas network regulation for the net zero transition – study for Catapult Energy Systems.

5.4 Long term

With the sector's maturity, policy priority would be to ensure markets can work in the long term. Guaranteeing this would require:

- Removing cross-sector distortions by moving away from any form of dedicated subsidies or support mechanisms; and
- Ensuring a cross-sector single carbon price drives energy choices.

Government involvement would be largely constrained to the regulation of networks and carbon markets.

5.5 Summary action plan

Adopting a long-term view of the green hydrogen sector requires considering the different stages of its lifecycle. These phases are introduction (near-term), growth (medium-term) and maturity or stabilisation (long-term). The role of government changes between stages, as summarised in Figure 31.

In the near term, the priority is ensuring the sector is up and running. To achieve this, we recommend:

- Adopting whole-system planning to ensure a cost-efficient green hydrogen integration in energy supply and provide relevant information to investors.
- Allocating support, building on the assessment of a whole-system analysis. We recommend support allocation favours coordination, covers the cost gap between green hydrogen and incumbent fuels and switching costs, and reflects the market's specificities. In Northern Ireland, this is focused on mobility and blending as anchor sectors.
- Engaging in regulatory adaptation to enable blending, favour network adaptation/roll-out, set out certification to capture end-users' willingness to pay, and strengthen investment in renewable energy sources.
- Implementing a Hydrogen Governance Body as a commitment and coordination vehicle between relevant stakeholders who can contribute to establishing a green hydrogen economy.

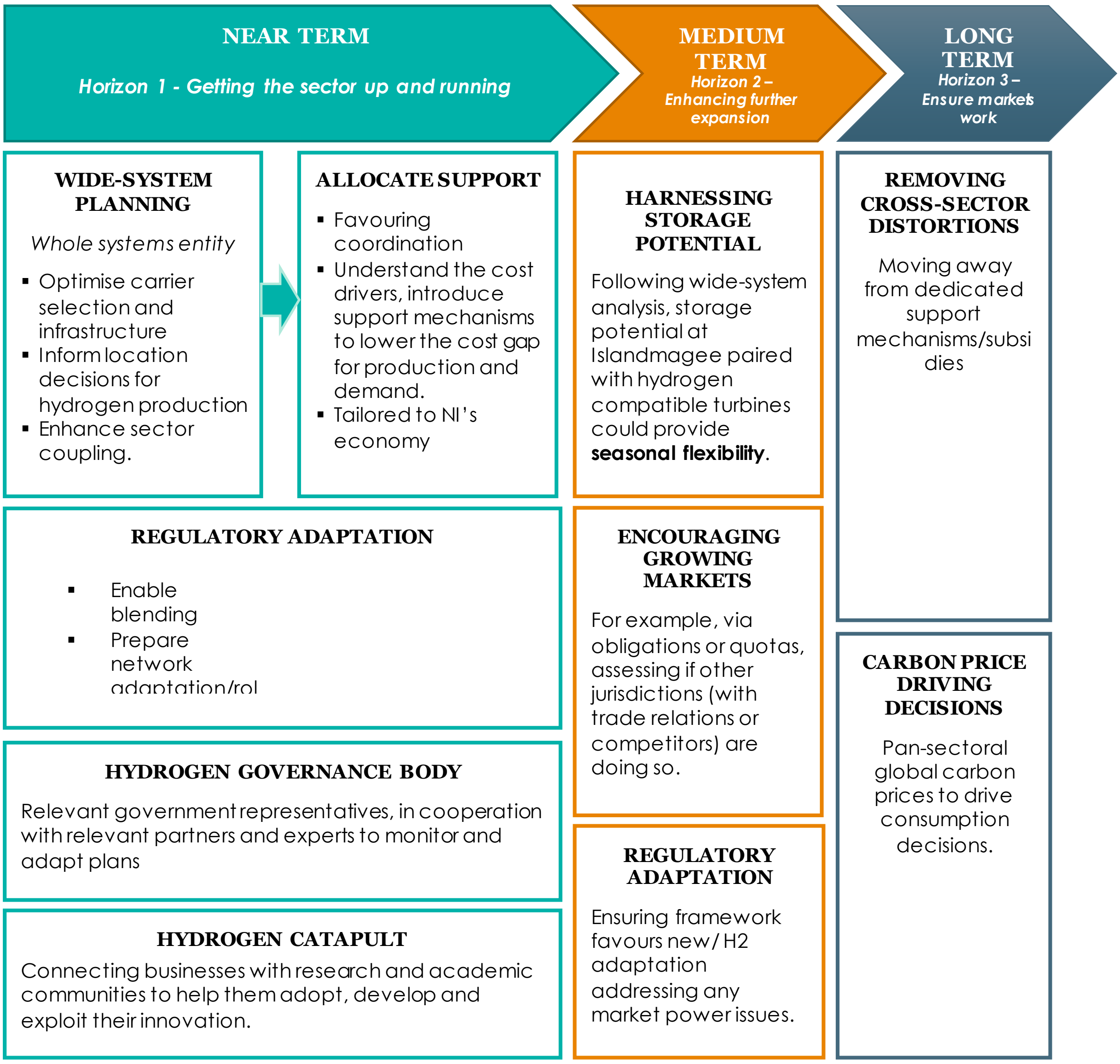
Considering Northern Ireland's ambition to contribute to the global hydrogen economy by providing technology development, we recommend prioritising the implementation of a hydrogen catapult as a near-term action. Doing so ensures maintaining momentum to deliver innovations when the global market has an appetite for it while favouring the sector's development in Northern Ireland.

In the medium term, we recommend favouring sector expansion by:

- Harnessing the storage potential at Islandmagee if doing so proves to be cost-efficient,
- Adopting growth-enhancing measures, such as quotas, if doing so does not compromise Northern Ireland's competitiveness,
- Engaging in regulatory adaptation tailored to the network needs if required.

In the long term, when the sector is mature, the policy priority is ensuring markets work by removing cross-sector distortions and enabling carbon prices to drive energy consumption decisions.

Figure 31. Summary action plan



Source: Frontier Economics

6 Wider impact

Developing a green hydrogen economy in Northern Ireland and strengthening its capabilities to participate in a global economy as a hydrogen technology developer has wider impacts on the economy. In this section, we discuss the effects on overall economic growth and do a deep dive into jobs and skills development.

6.1 A green engine for growth

Establishing a green hydrogen sector involves introducing new economic activities that contribute to Northern Ireland's Gross Value Added (GVA). The direct effect of these activities on GVA is likely to be less significant than the benefit green hydrogen integration has on the overall economy. We cover potential direct GVA impacts in Annex E, but this section focusses on the potentially more significant effect on growth associated with providing a cost-effective source of green energy.

Sustainable economic growth requires an appropriate green engine to fuel all economic activities. Energy supply is fit for this purpose when it is sustainable, secure and competitive. Integrating green hydrogen in the energy matrix enhances these three criteria.

Green hydrogen provides a decarbonisation alternative for hard-to-electrify sectors, most notably within the energy-intensive industry, for example, chemical production, steel, cement and glass. Green hydrogen may be more cost-effective to decarbonise sectors where direct electrification is possible. Examples may include heavy transport, less energy-intensive industry and heat.

Whole-system planning is critical to determine which alternative delivers the larger net social benefits. Aspects such as costs to deploy additional production capacity, adapt or extend network and storage infrastructure, and end-user appliance costs shape the cost-competitiveness of alternatives. The assessment is specific to each jurisdiction. There is no one-size-fits-all approach, reinforcing the need for comprehensive sector planning.

Efficient decarbonisation of energy supply translates into:

- **Economic competitiveness,** ensuring Northern Irish products can compete domestically with potential imports and international markets. The European Union is the UK's largest exporting market. Ensuring cost-efficiency of energy supply is critical to remain competitive in the context of a Carbon Border Adjustment Mechanism setting a tax on product-embedded emissions (see Annex D)

- **Alignment with customer preferences**. In the UK, and globally, there is increasing interest from private and public buyers and investors in the climate impact of products, as the formation of international initiatives on emissions reporting and market development for low emission products advances.[75]
- **Green hydrogen also enhances security of supply.** Security of supply relates to the certainty of delivering energy when needed, based on domestic factors and the diversity and reliability of trading partners. Harnessing its significant renewable potential, Northern Ireland would be able to produce green hydrogen, increasing the contribution of domestic energy supply to meet demand. More generally, the portfolio of green hydrogen supply is more diversified than incumbent fossil fuels, with more countries being able to participate in a global market with their green and low-carbon hydrogen. Diversifying the trading partners for energy supply (or back-up, assuming domestic production is sufficient) enhances security of supply.

6.1.1 Jobs

The economic benefits of developing a green hydrogen economy also extend to jobs. The largest contribution is in enhancing the competitiveness of the Northern Irish economy by contributing to an appropriate green engine, as discussed in the previous sub-section. A competitive economy sustains jobs in all economic sectors.

As discussed earlier, establishing a green hydrogen economy in Northern Ireland also creates new economic activities. These activities could directly support new jobs, however, this impact is minor compared to the benefit on all jobs linked to having a green engine fuelling a competitive economy.

Following stakeholders' interest, we do a deeper dive on this (minor) impact on jobs and the corresponding implication on skills. Our methodology follows the analysis of BEIS[76] and Element Energy.[77] The approach consists of identifying benchmarks for the new activities that green hydrogen will create and drawing lessons from those referents. Annex E further describes the methodology and assumptions.

We note that the methodology assesses the jobs supported by additional activity in the hydrogen economy. These should not be interpreted as net additional jobs as we do not take account of displacement and substitution: for example, the extra jobs generated in renewable sectors may to some extent be offset by reductions in

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[75] BEIS (February 2022) Call for Evidence: Towards a Market for Low Emissions Industrial Products.

[76] BEIS (October 2019) Energy Innovation Needs Assessment: Overview Report.

[77] Element Energy (November 2019) Unlocking Jobs and GVA whilst reducing emissions in the UK.

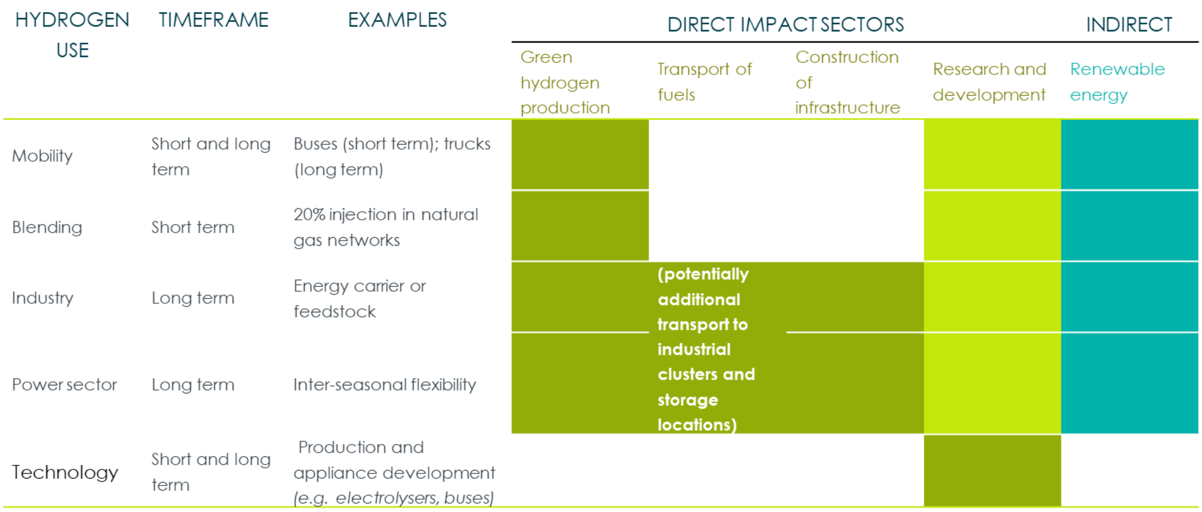
employment in traditional power generating sectors, so that it is possible that the net employment impact could be zero or negative.

Figure 32. Summary approach to assess potential job creation linked to a hydrogen economy

Source: Frontier Economics

The starting point of the analysis is the vision and objectives for developing a green hydrogen economy, presented in Sections 0 and 3.2. Figure 33 summarises the sectors where we expect new economic activities to appear linked to the realisation of that vision.

Figure 33. Identifying hydrogen economy impact sectors

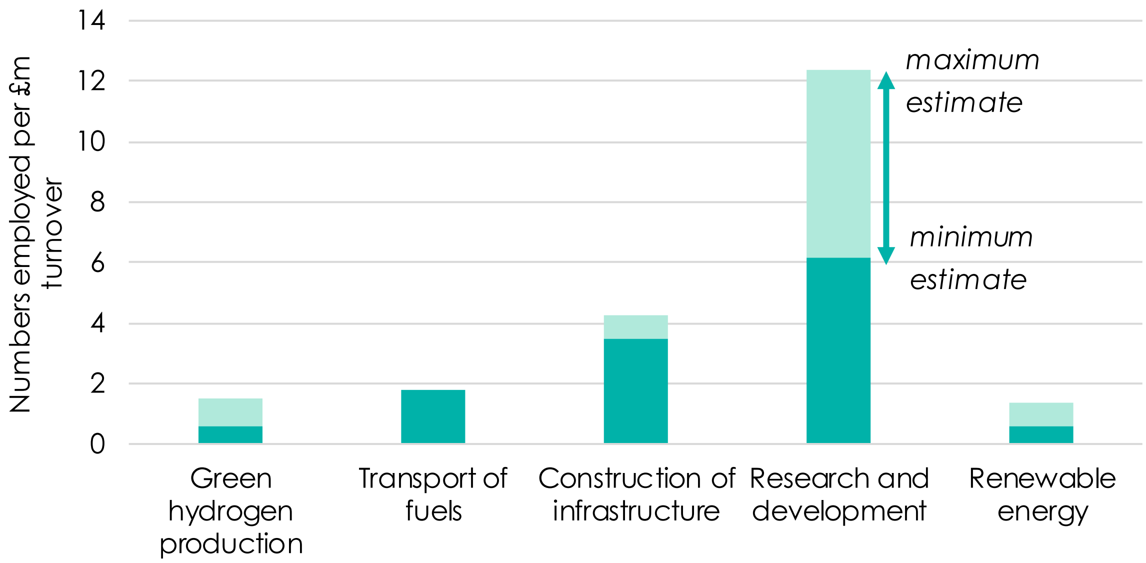


Source: Frontier Economics

In order to draw lessons from these sectors about the potential implications on jobs, we assess their employment intensity measured as the number of people employed per unit of turnover (see Figure 34). Employment intensity indicators suggest that

£247m private investments[78] in Northern Ireland could support 575 – 870 jobs (considering production, transmission and distribution only) in 2030[79].

Figure 34. Employment intensity in reference sectors



Source: Annual Business Survey 2019; Business Register and Employment Survey 2019 - Northern Ireland (NISRA); Business Register and Employment Survey 2019 – Great Britain (ONS via nomis.web); Frontier calculations

Notes:

(1) Estimate ranges are derived from both UK and Northern Ireland referent employment intensity data: see Annex for full methodology.

(2) In the transport of fuels sector, we only have one estimate taken from UK-level data: the Northern Ireland-based estimate was not judged to be representative as the industry category includes passenger and freight transport.

(3) The wide estimate range for the Research and Development industry is driven by large differences in the estimates for the UK and for Northern Ireland (NI estimates are higher for both GVA and employment ratios). This could be representing a higher GVA and employment intensity in NI or could be a feature of a smaller sample size because of a smaller overall industry in NI. We present both estimates for reference.

These indications from the analysis of employment intensity in reference sectors are broadly consistent with estimates building on UK analysis. According to the UK Hydrogen Strategy, the UK hydrogen economy could support over 9,000 jobs by

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78 UK government expects hydrogen to deliver up to £ 4bn private investments (see See Fuel Cells Works (2021) Hydrogen NI Launched to support growth of Northern Ireland's Hydrogen Economy) by 2030 for a target capacity of 5 GW.

Following our study for NIE, capacity in Northern Ireland could be 0,3 GW by 2030 for domestic consumption of 2 TWh. The proportional private investments would be £ 247m.

79 Following the BEIS methodology, this estimate does not take account of substitution, leakage or displacement effects (for example the risk that jobs are displaced in other sectors).

2030 and up to 100,000 jobs by 2050. Proportionately, the jobs supported in Northern Ireland could be 555 in 2030 and 3,403 in 2050.[80]

UK Energy Research Centre's systematic literature review[81] provides additional insights about the impact on jobs. In particular, this review finds that:

- Low-carbon energy may deliver more jobs than gas or coal power generation.
- While green jobs tend to be more highly skilled compared to higher carbon occupations, this sector also demands lower-skilled, manual occupations.
- Green skills supply and demand should be carefully managed through policies supporting green job creation and coordination of training activities.

In fact, the availability of skills shapes employment opportunities in the activities that a green hydrogen economy stimulates. We therefore assess the skills required and propose actions to bridge gaps where needed.

Skills assessment

Skills underpin job opportunities linked to the development of a green hydrogen economy. At the same time, skills support the sector's progress. To understand the availability of skills for a green hydrogen economy in Northern Ireland, we reviewed the Northern Ireland Skills Strategy[82] and a UK study by Element Energy[83] of the implications of the transition towards Net Zero for the engineering construction industry. Stakeholder engagement contributed with additional valuable insights to better assess the skills landscape.

The Skills Strategy suggests the areas of more significant skills gaps in Northern Ireland relate to hydrogen economy sectors, most notably, engineering and manufacturing technologies and science and mathematics. Construction, planning and the built environment also face gaps, albeit smaller than the previous.

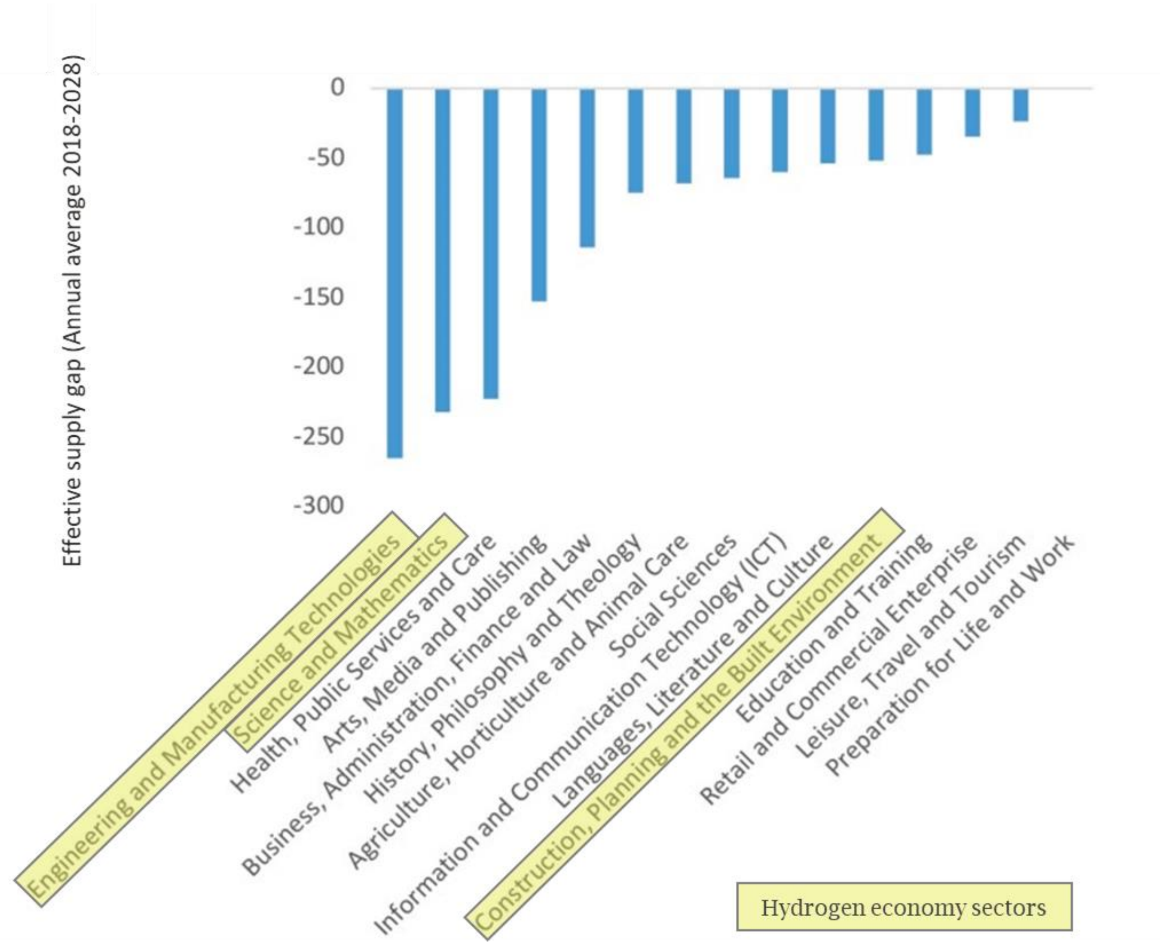
80 Considering consumption up to 2 and 6.8 TWh in 2030 and 2050 (following our study for NIE) and 74% efficiency. Takes proportion regardless hydrogen production technology.

81 UK Energy Research Centre (April 2022) Green job creation, quality and skills: A review of the evidence on low carbon energy.

82 Department for the Economy (2022) Skills for a 10x Economy – Skills Strategy for Northern Ireland. Available online at

83 Element Energy (2020) *Towards Net Zero: The implications of the transition to net zero emissions for the Engineering Construction Industry.*

Figure 35. Skills shortages identified in mid-level professional and technical education



Source: Frontier Economic based on Northern Ireland's Skills Strategy[84]
Notes: The chart represents the annual average effective supply gap by NQF level 4-5 subject (SSAs, 1-digit), NI (2018- 2028)

Element Energy's study for the UK considers the newly created sectors of the hydrogen economy (e.g., producing green hydrogen, pipeline construction), and in sectors expected to use green hydrogen for example through new industrial processes. The study conducts this analysis in terms of 'skills disruption': higher disruption is expected in areas where the future skills required to produce and use hydrogen are not currently available. We have identified additional sectors for skills assessment based on the vision for the Northern Irish economy, expanding the list of sectors to include hydrogen use in mobility and blending, and assessing potential skills disruption based on information from stakeholder engagement. The analysis

[84] Department for the Economy (2022) Skills for a 10x Economy – Skills Strategy for Northern Ireland.

suggests that more significant skills gaps could be present in the use of hydrogen for blending and storage.

Figure 36. Skills disruption by sector in the hydrogen economy

HYDROGEN TECHNOLOGY	SKILLS DISRUPTION	RATING
Green hydrogen production	Minor upskilling for commissioning, installation, start-up, and testing of electrolysers	
Fuel transport	Existing skills with minor training on pipes materials suitable for hydrogen	
Pipeline build-up (pipelines)	Minor upskilling needed for use of new materials and asset testing	
Research and development**	Existing sector	
Renewable energy production**	Existing sector	
Hydrogen use – mobility*	Local manufacture already developed. Stakeholder engagement suggests training in development	
Hydrogen use – blending*	Stakeholder engagement suggests training in development	
Hydrogen use – industry	Existing skills similar to chemical industry, upskilling required for cracking and storage	
Hydrogen use – storage (potential)	Upskilling in FEED, developing technical and safety plans and operative training	
Hydrogen use - heating (potential)	Existing skills for appliance installation and operations	

Skills disruption: Low, Medium, High

Source: TOWARDS NET ZERO: The implications of the transition to net zero emissions for the Engineering Construction Industry (Element Energy, 2020)

*Note: FEED = Front End Engineering Design * Following stakeholder engagement. ** Following Northern Ireland Energy Strategy*

In the following section we recommend actions to bridge the skills gap.

Actions to bridge the skills gap

The Skills Strategy recognises the importance of developing knowledge and skills in the low-carbon sectors to ensure that these can grow.[1] Moreover, it is expected that the growth of the green hydrogen sector will generate skills disruption in some of the subsectors involved. In Section 6.1.1 we explored the wider impacts that are expected to be generated by developing a green hydrogen sector in Northern Ireland. In particular, we noted that in some subsectors there could be skills shortage either because of needing more people with the existing skills, as well as needing to train people in new technologies and processes. For this reason, it is crucial that actions are in place to equip the sector with the right set of skills that will enable its development. We identified three main actions we recommend implementing in the nearest term as well as two overarching principles that should guide how these develop in the longer run.

Figure 37. Actions and principles recommended to bridge the skills gap

Source: Frontier Economics

Identify the skill gaps in the sector through engagement with the industry. The first action that we recommend is to identify the gaps in skills needed to kick-start the sector. Particularly, it will be important to identify which skills are already in place, which are not and how many people are equipped with these. It will also be important to identify which complementary skills[85] are needed.

- We envisage different channels through which this first action can be carried out. Firstly, we expect that wider initiatives promoted for the decarbonisation of Northern Ireland will be informative also for the case of the green hydrogen sector. For example, we recommend relying on the Energy Skills Audit[86], the Northern Ireland Skills Forum and Energy Skills Forum[87] planned to be run by the Department for the Economy in the near and medium term.
- Moreover, we suggest that this process is undertaken in consultation with the industries that are expected to be involved in the development of the hydrogen sector. We suggest building this from previous experiences of cooperation between training entities and the industry. For example, our stakeholder engagement underlined that universities and technical colleges have a history of close collaboration with the industry. Also, the Hydrogen Training Academy pilot sets a useful example where the identification of the skills gaps and the trainings are based on industry feedback received via the Manufacturing Taskforce.

[85] Complementary skills are additional skills that, once combined, become more effective in accomplish a specific goal.

[86] DfE (2022). Energy Strategy for Northern Ireland. The path to Net Zero energy. Action Plan 2022.

[87] DfE (2021), Energy Strategy - Path to Net Zero Energy.

Developing the training content. Once skills gaps are identified, the second step will be to develop the content of the training that is required. Once again, the process can be either carried out within the relevant training bodies (such as universities and technical colleges) after they have gathered feedback from the industry. Alternatively, as the Hydrogen Training Academy pilot shows, the design of the training content can be delegated from local authorities to specific task forces which will be also in charge of instructing the trainers. At this stage, we believe that the development and the delivery of the training will be facilitated by good links in place with the wider UK and EU industry. In this way we expect that Northern Ireland will be part of wider discussions around hydrogen and it will stay at the cutting edge of best practices and innovation.

Delivering the training. As a final step, it will be fundamental to deliver the training. This can be done through different institutions and in different ways. In any case, it is important that the trainings are delivered so that that skills are available where and when they are needed. This will avoid the lack of skills in specific parts of the sector acting as a bottleneck for its development.

We recommend that the three actions mentioned above are implemented in the immediate future. We suggest keeping into consideration two overarching principles that should guide the implementation of these actions and how to progress over a longer horizon.

Training should ensure upskilling in the traditional sectors. The development of the hydrogen sector could displace some jobs in traditional industries (for example fossil fuel supply). For this reason, it will be important that upskilling and reskilling training is available for people currently working in those sectors. For example, this would mean that the training delivery is compatible with work schedules. Not only will this enable the development of the green hydrogen sector, but it will also contribute to the wider objective of the Northern Ireland to create a culture of lifelong learning[88].

In the medium and long term, training should adapt to the market's evolution. As we mentioned in section 4.1, we expect that the green hydrogen sector will evolve over time. As a consequence, the skills needed to ensure its growth are also expected to change over time. For this reason, we suggest that the Northern Ireland Skills forum or other relevant training bodies would take part in the Hydrogen Government Body (see section 5.1.4). We envisage that this will allow the bodies in charge of implementing the actions mentioned above to have first-hand information on how the sector is expected to evolve, ensuring that trainings are updated accordingly.

[88] DfE (2022) *Skills Strategy for Northern Ireland. A consultation.*

Moreover, this will create a further channel of communication with policy makers and the industry and will provide insights to the relevant training bodies on how other actors are operating in the sector. Finally, having the relevant training bodies sitting in one place would ensure that synergies are captured, and duplication of efforts are avoided.

annexes

Annex A. Steering Committee

- Rob Grundy – Chair of Matrix
- Alistair Jinks - Northern Ireland Water
- Andrew Benfield - Department for the Economy
- Edward Kerr – Department for the Economy
- Andrew Woods - Catagen
- Grainne McVeigh - Invest Northern Ireland
- James Carton - Dublin City University
- John Green - Strategic Investment Board Northern Ireland
- Juliana Early – Queen's University Belfast
- Neil Hewitt - Ulster University
- Patricia O'Hagan - Core Systems
- Paul Maropoulos – Queen's University Belfast
- Paul McCormack - Belfast Met
- Paul Stapleton - Northern Ireland Electricity Networks
- Rory Monaghan - NUI Galway

Annex B. Stakeholders participating in workshops

- Artemis Technologies
- B9 Energy
- BEIS
- Belfast City Council
- Belfast Met
- Belmont Strategy
- Catagen
- CCP Gransden
- CPH2
- DAERA
- DfE
- DfI
- EirGrid
- Gas Market Operator for Northern Ireland
- Gas Networks Ireland
- GO Power
- HSE NI
- Innovate UK
- Invest NI
- KCS NI
- Kingspan
- Kinkead Consulting
- Lagan MEICA
- Lagan Specialist Contracting
- Linamar
- Mid and East Antrim Borough Council
- MJM Renewables
- Mutual Energy
- National Grid
- NI Water
- NIE Networks
- Northern Ireland Networks
- NUI Galway
- Phoenix Natural Gas
- Queen's University Belfast
- Renewable Northern Ireland
- Ross Planning
- SGN
- Shoosmiths
- SONI
- Spirit AeroSystems
- Strategic Investment Board
- Terex
- Translink
- Ulster University
- Utility Regulator

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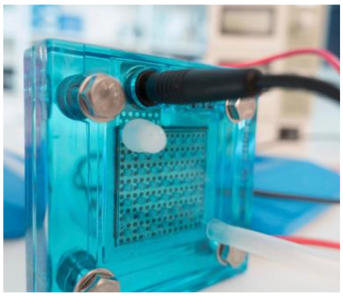
Annex C. Detailed assessment of barriers and enablers

This annex summarises our detailed assessment of barriers and enablers to develop a green hydrogen economy in Northern Ireland. While our first workshop was dedicated to this aspect, continued engagement with stakeholders contributed to review the analysis initially discussed during the workshop and presented in an interim report delivered on April 1, 2022.

Barriers and enablers are those conditions in the economy that respectively prevent and support the sector's development and its possibility to create jobs. Understanding these barriers and enablers informs the design of an action plan to develop a green hydrogen economy in Northern Ireland. We initially assessed these barriers and enablers in three categories (Figure 38):

Figure 38. Categories of barriers and enablers

Technology



Technological developments (R&D) for production and cost savings

Investment and Supply

Conditions for investment in the low-carbon hydrogen industry

Markets and Demand

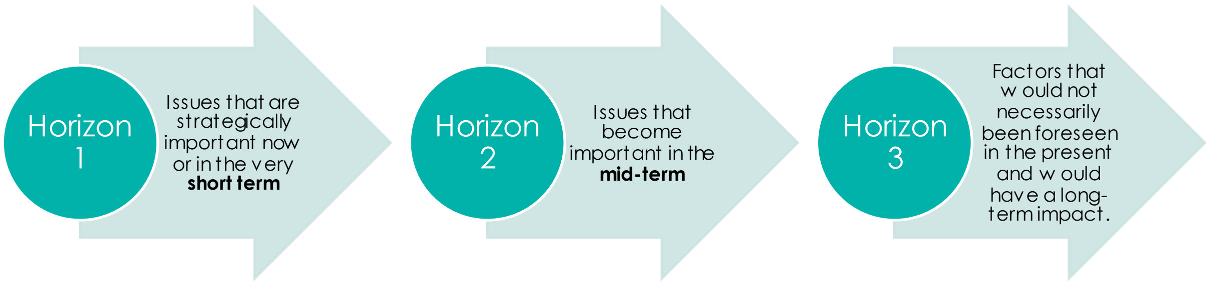
Realisation of demand opportunities, giving place to new markets

Source: Frontier Economics

Following the UK Futures Toolkit,[89] we classify barriers and enablers across time frames or horizons (Figure 39). Strategic considerations shaping opportunities in the short-term – from today to 2030 – correspond to Horizon 1. Those with increased influence in the market towards the mid-term – between 2030 and 2040 – belong to Horizon 2. Factors most relevant to the longer term impact are allocated to Horizon 3.

[89] Government Office for Science (2017) The Futures Toolkit

Figure 39. Three Horizons



Source: Frontier Economics

This annex presents our assessment. For each pillar, outlines the barriers and enablers.

C1. Technology barriers and enablers

Table 3 summarises the barriers and horizons relating to technology over the three horizons.

Table 3. Technology barriers and enablers

	HORIZON 1 (UNTIL 2030)	HORIZON 2 (2030-2040)	HORIZON 3 (BEYOND 2040)
Barrier	Chicken-and-egg issues: ▪ Investment is needed on the supply and demand side ▪ Cost reduction requires upscaling demand		
Enabler	Local expertise in technological development.	Early examples of projects enabling dual-uses of hydrogen.	
Strategic risk	Ensuring technology support to the sector development translates to domestic job creation.		

Barriers: Indirect substitution and high costs

Two key barriers challenge the creation of a green hydrogen economy, in the Horizon 1 timeframe:

Indirect substitution creates a chicken-and-egg problem. Developing the sector requires **concurrent investments along the value chain**, not only at the supply level. The majority of potential demand sectors for green hydrogen consume natural gas and conventional liquid fuels today. This means that green hydrogen is not a direct substitute for the incumbent fuels[90]. Substitution to green hydrogen requires adapting end-user appliances and industrial kit[91] as well as some new transport and storage infrastructure.

- Consumers may be hesitant to invest in new appliances and kits until production, transport and storage infrastructure are in place. At the same time, producers and investors in transport and storage infrastructure may also be unwilling to invest, absent certainty around the demand and supply.
- This barrier, which is common in all jurisdictions aiming to develop a green hydrogen economy, may be particularly problematic in Northern Ireland because of the nature of its industrial sector. Absent large industrial centres, starting the sector development around industrial clusters as planned in various other jurisdictions[92] is not possible in Northern Ireland.

High costs and economies of scale create another chicken-and-egg problem. Green hydrogen is significantly more expensive than incumbent fuels, and so are its derivatives. This cost gap further discourages consumers from substituting. Doing so increases their costs of energy procurement. At the same time, achieving cost reductions require scaling-up demand. We refer to this as another chicken-and-egg situation, whereby upscaling is necessary to lower cost, but the demand requires a low cost to substitute.

Enablers: Local expertise in technological development

Northern Ireland has developed local expertise in green hydrogen technologies, relevant to the Horizon 1 timescale. This is evidenced by the presence of various

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90 In contrast for example, to situations where green hydrogen would be substituting for grey hydrogen in industrial applications.

91 Unless synthetic methane or liquid fuels with significantly higher production costs are used.

92 Portugal, Australia and Germany include the creation of industrial clusters as one of the actions to develop the sector.

patented technologies[93] for hydrogen production. This expertise could contribute to the vision of Northern Ireland participating in a global hydrogen economy as a technology provider.

The region has an **early example of projects enabling dual-uses** of hydrogen generating technologies – Lagan MEICA JV.[94] The Project installs a membrane-free electrolyser at NI Water's plant in Belfast to produce up to 3,609 kg of medical-grade oxygen and 451 kg of hydrogen per day. Oxygen is used for water purification, leaving hydrogen available for energy uses. By enabling cost-sharing, multipurpose projects lower the costs of hydrogen production. Exploring wider opportunities favours cost reduction. Again, this could enable expansion over Horizon 2.

C2. Investment and supply

Table 4 summarises the barriers and enablers relating to investment and supply over the three horizons.

Table 4. Investment and supply: Barriers and Enablers

	HORIZON 1 (UNTIL 2030)	HORIZON 2 (2030-2040)	HORIZON 3 (BEYOND 2040)
Barrier	▪ Uncertain support mechanisms for green hydrogen and green synthetic liquid fuels in Northern Ireland. ▪ Uncertainty about the regulatory framework for electrolyser/green hydrogen generation management. ▪ Uncertainty about the regulatory framework for blending. ▪ Missing overarching energy system planning and overview. ▪ Issues in the electrolyser supply chain, especially delivery. ▪ Stalled wind capacity.	▪ Insufficient skills to maintain and operate transmission and distribution networks in the context of blending and dedicated infrastructure.	

[93] For instance, Dr. Nigel D. L. Williamson, Clean Power Hydrogen Technology Director & Co-founder, holds over 160 patents worldwide for his hydrogen and sealing technology designs. One of these patents is for a membrane-free electrolyser.

[94] Hydrogen East (March 26, 2022) Clean Power Hydrogen and NI Water join forces to reduce emissions.

	HORIZON 1 (UNTIL 2030)	HORIZON 2 (2030-2040)	HORIZON 3 (BEYOND 2040)
Enabler	▪ Significant wind resource in the island of Ireland and a wider renewable potential.		▪ Significant seasonal storage potential in salt caverns.
	▪ Modern polyethene gas network without compressors minimises technical constraints for **blending.**	▪ Modern polyethene gas network without compressors minimises technical constraints for **grid conversion.**	

Source: Frontier Economics

Barriers: Gaps in policy, regulation and coordination

We identify five barriers to supply investment and materialisation. We classify four of these in Horizon 1 and the other in Horizon 2.

Support mechanisms for green hydrogen and green synthetic liquid fuels are not yet in place. Lack of support – and to a lower extent, uncertainty about it – could compromise the sector development, with the first projects being out of money and exposed to high financing costs largely resulting from uncertainties in delivery and demand. Investments in the sector entail learning externalities – given its early stage – in addition to decarbonisation externalities. The fact that social benefits from projects are larger than those investors can privately enjoy, means that private investments would be less than socially desirable absent support.

BEIS undertook UK-wide consultation on business models.[95] The exact form of the support is still unknown, and its application to the region is uncertain. Further information on the design of hydrogen business models is expected in Spring 2022. We will review the proposed business model and its appropriateness to foster the sector in the region. In the meantime, we note the following.

The current proposals for business models are complex, and may be more suited for very large investments, where the fixed costs of engaging with the detail of the policy can be more easily managed. This may make them less suitable for green hydrogen development since these tend to be smaller projects.

Potential price indexation of contract-for-difference support to natural gas prices may also better suit blue hydrogen production (by providing a degree of natural hedge to its input price), and to low-carbon hydrogen applications substituting away from natural gas. Considering a significantly larger consumption of oil products

95 BEIS (August 17, 2021) Design of a business model for low carbon hydrogen.

in the region, this support leaves interested parties exposed to oil/natural gas divergences. The latter is a risk that is complex to hedge.

Uncertainty about the regulatory framework for electrolyser/green hydrogen production management compromises power networks' ability to connect renewables to the grid, which may slow the development of green hydrogen production. SONI's Annual Innovation Report indicates a potential high risk of denying connection absent resources – including skills – ensuring the integration of green hydrogen production respecting system constraints.[96]

While green hydrogen production may develop off-grid, the expectation is that most of the production would connect to the grid.[97] Stakeholders particularly highlighted the long-time lags associated with network planning as a risk.

It will be possible to manage this, but the tools are not yet in place. Networks operators require evaluating how to adapt their system operation commercial and regulatory framework to avoid those situations and maximise green hydrogen's potential services to the grid.[98]

Blending also faces regulatory uncertainty. With today's framework assuming a relatively uniform gas quality, the main aspects to consider when evaluating the framework include:[99]

- managing the blend and gas quality, ensuring that hydrogen blend is kept within the blend limit,
- establishing an appropriate allocation of network capacity to hydrogen producers,
- managing specific requirements of certain user types (from those who cannot take any hydrogen to those that could take up to 100%),
- ensuring that distribution and transmission charges facilitate competition in a hydrogen blended system (with potentially increased injections at the distribution level), and

96 SONI (February 2022) 2021 Annual Innovation Report. Page 55.

97 Ibid. Page 52.

98 Ibid. Green hydrogen generating units connected to the grid may provide frequency and voltage support and demand response, mid and long-term storage and cross-sector energy balancing enhancing the System Operator's toolkit within the electric system and surrounding energy sectors (heat & cool, thermal storage, water desalination, multi-fuels engines, etc.).

99 Frontier Economics (September, 2020) Hydrogen Blending and the Gas Commercial Framework. Report on conclusions of a NIA study for Cadent.

- adjusting billing to final customers to reflect different calorific values at different points of the grid.

The draft GD23 determination draws attention to this gap, indicating that further work will be required to develop policy, regulation and practical solutions to decarbonise gas networks – including enabling hydrogen injection. Lack of a blending framework poses limitations to developing demand potentials in buildings

Lack of an overarching energy system planning and overview – most notably transmission/distribution and storage infrastructure in the electricity and gas sectors – could slow down investments in hydrogen production. This analysis informs costs, project design and location,[100] access to the demand and the possibility to balance supply to ensure a reliable supply. Concerning this gap, SONI's Annual Innovation Report refers to the need of power and grid gas coordination in planning assessments to include power-to-hydrogen and power-to-product more generally.[101]

Stalled wind deployment in the island paired with high electricity prices may constitute an additional barrier. The latter intensifies the competition from electricity uses – for instance, green corporate Power Purchase Agreements (PPAs) – to the hydrogen sector. The halted renewable expansion could obstruct a green hydrogen sector development. Indications of a strong pipeline of incoming projects, with networks receiving various connection requests, suggest that this concern may not constitute a barrier in the short term. We therefore classify it into the Horizon 2. It requires close monitoring to take early action before renewable capacity constrains green hydrogen development.

Stakeholder consultation further indicated **insufficient skills to maintain and operate transmission and distribution networks** in the context of **blending** and **dedicated infrastructure.** We classify this strategic issue in the Horizon 2: it would not halt the sector development at early stages but could reduce the domestic job creation potential and increase costs – by requiring the import of skills to provide those services.

Stakeholders also highlighted **supply chain issues in the very near term** – in particular the long lag associated with the delivery of electrolysers after ordering (up to 2 years). This could reduce the ability of the sector to exploit near term opportunities. It

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[100] Investors require an infrastructure overview to assess the implications of their location decisions. Should they locate onshore or offshore? Should they plan direct power lines or pipeline deployment?

[101] SONI (February 2022) [2021 Annual Innovation Report](). Page 54.

could also mean that even generous support may not be enough to stimulate the green hydrogen economy in the very near term.

Enablers: Significant wind resources, a modern gas network and significant seasonal storage potentials foster investment and supply

The **significant wind resource** in the island of Ireland and a **wider renewable potential** provides a solid foundation to develop a green hydrogen economy. The potential could be further expanded in the long-term, with tidal and geothermal energy complementing wind capacity.

Northern Ireland's **modern polyethene gas network** without **compressors** minimises technical constraints for blending during Horizon 1. Polyethene pipelines are compatible with hydrogen pipes. Blending increases concerns for compressors' corrosions, explaining why blending presents technical challenges that are absent in Northern Ireland. Favourable conditions to blend at early stages allow heat to act as one of the potential anchors to develop the sector. The modern gas network could also help grid conversions over Horizons 2 and 3.

Further down the line, at stages of more scaled green hydrogen demand, Northern Ireland's significant **seasonal storage potential** in salt caverns – like that at Islandmagee[102] – provides a valuable basis for hydrogen to enhance security of energy supply. Salt caverns offer a promising option for long-term storage, and evidence suggests losses in hydrogen storage are minor and not time dependent.

[102] ENTSOG (2020) Ten year development plan (p. 768),

C3. Markets and demand

Table 5 summarises the barriers and horizons relating to markets and demand over the three horizons

Table 5. Markets and demand: barriers and enablers

	HORIZON 1 (UNTIL 2030)	HORIZON 2 (2030-2040)	HORIZON 3 (BEYOND 2040)
Barrier	▪ Indirect substitution from natural gas and conventional liquid fuels towards green hydrogen. ▪ Cost gap between hydrogen, its derivatives and incumbent fuels. ▪ Lack of certification identifying the green character of green hydrogen and its derivative liquid fuels.	▪ Complex exporting conditions. ▪ Missing skills for hydrogen end use.	
Enabler	▪ Manufacturing of hydrogen-fuel buses based in Northern Ireland. ▪ Hydrogen Training Academy.		

Source: Frontier Economics

Barriers: Indirect demand substitution and the high cost gap create the main barriers for markets and demand materialisation in the short term

Two barriers may impede efforts to upscale the market in the short term or Horizon 1. The first two barriers have already been discussed in Section 4.2 above:

Most of the potential demand for hydrogen consumes natural gas and conventional liquid fuels today. **Substitution** from these towards green hydrogen is **indirect** unless it is used to produce green synthetic fuels at higher costs. Indirect substitution requires users to engage into one-off appliance adaptation costs to substitute towards a most expensive carrier. Consumers also require minimum reliability/ security of supply – for instance, from storage – to decide to substitute. As the sector develops, it could be mitigated with network/storage investment.

The significant **cost gap** between green hydrogen, its derivates, and incumbent fuels means that, absent support and policy direction, users would not have incentives to substitute towards these products. Alternative significant increases in carbon costs would clash with industrial policy objectives and affordability.

BEIS has currently introduced a number of demand-side schemes (Figure 40). However, funding for these is limited and focuses on the industry (except for the second scheme), reducing its pertinence for Northern Ireland.

Figure 40. Demand side support schemes

Industrial energy transformation fund (Phase 2)

- Aims to de-risk key technologies including hydrogen fuel switching by providing support for feasibility and engineering studies, and capital support for first movers to upgrade their industrial equipment.
- It will increase readiness for the hydrogen economy by building demand for hydrogen in industry and helping to develop the commercial case for low carbon hydrogen projects

Red diesel replacement competition

- Aims to support the development and demonstration of innovative technologies that enable Non-Road Mobile Machinery (NRMM) used for quarrying, mining, and construction to switch from red diesel to hydrogen or other low carbon fuels.

Industrial fuel switching 2 competition

- Aims to develop and demonstrate innovative solutions for industry to switch to low carbon fuels such as hydrogen.
- The latest round of funding was awarded in winter 2019, with four projects moving from feasibility studies to demonstration.

Further down the line, we identify three barriers to widening the market.

The first one is a **lack of certification** identifying the green character of green hydrogen and its derivative liquid fuels. Certification instruments are necessary to market products as 'green' and to capture consumers' willingness to pay a premium for green products. **Certification** will also be very important in the export market.

Complex exporting conditions may be another barrier to further expanding the green hydrogen market produced in Northern Ireland via exports. Complex conditions involve:

- **Lack of a hydrogen taxonomy** in major importing economies, for instance, the EU. The latter is under discussion as part of the Renewable Energy Directive revision (RED III) and its delegated act on fully renewable fuels of non-biological origin.
- **Efficiency losses associated with shipping hydrogen.** Hydrogen compression and transformation into ammonia, synthetic methane, liquid hydrogen and liquid organic hydrogen carriers involve efficiency losses (Figure 41). These efficiency

losses mean that green hydrogen production in Northern Ireland will have to be significantly cheaper to produce than in the export destination (e.g., Germany) to compete.

Figure 41. Options for shipping hydrogen

Ammonia

- Hydrogen is converted to ammonia, shipped, and reconverted to hydrogen via 'cracking'
- Ammonia shipping is already well-established technically

Syn-methane

- Hydrogen is methanated (via adding CO2) to produce synthetic methane, which is then shipped at -163C and regasified at a methane reformation plant
- Natural gas transportation is well established

Liquid hydrogen

- Hydrogen is liquified at -253C, transported by ship, and regasified at the import terminal
- Process is very inefficient and expensive due to cooling equipment required. Liquid H2 ships do not exist commercially today

LOHC

- Hydrogen is attached to a carrier via hydrogenation, shipped at 20C, and reconverted via dehydrogenation and compression
- Efficiency is low (overall 20-30%), however LOHC are relatively easy to transport with existing infrastructure

Finally, missing **skills** to operate and maintain **hydrogen end-use** appliances may increase end-users' costs, exposing them to imported skills. It also compromises the ability of the sector to create jobs in Northern Ireland. This barrier may be less pressing in Northern Ireland if green synthetic liquid fuels become the specialism area of the sector. By involving a direct substitution from conventional liquid fuels, incumbent appliances and skills to operate and maintain them remain relevant.

Enablers: Domestic production of buses and the hydrogen skills academy appear as good basis to upscale demand

Wrightbus is a Ballymena-based bus manufacturer, **manufacturing hydrogen-fuel buses**. Given that mobility appears to be one of the anchor sectors in the country, it is an advantage that hydrogen buses are already produced in Northern Ireland to ensure job creation related to this activity.

Ballymena's **Hydrogen Training Academy** – aiming to train operators and manufacturers of end-use applications – sets a good foundation to tackle concerns around skills. Expanding its reach to all interested parties in Northern Ireland would foster job opportunities linked to the sector development.

Annex D. International case studies of hydrogen strategies

D1. Portugal

The Portuguese National Energy and Climate Plan 2021 -2030 (PNEC 2030) sets out the main policies and measures that Portugal is planning on taking to achieve carbon neutrality in 2050. In particular, the plan sees hydrogen as a fundamental vector for the decarbonisation of various sectors.

To do so, Portugal has developed a National Hydrogen strategy[103] with the aim to facilitate and accelerate the energy transition by incorporating hydrogen in various sectors of the economy.

Below we list the initiative that the Portuguese Government has already in action.

Technology

- **Implement a collaborative laboratory (CoLab):** the strategy aims to create a collaborative laboratory which will develop R&D activities around the main relevant components of the hydrogen value chain. The purpose of this is to boost the development of new industries and services, based on highly qualified human resources.

Investment and Supply

- **Industrial project for the production of green hydrogen in Sines:** there is an ongoing project of industrial scale to install at least 1 GW of green hydrogen production.
- **Enhance synergies with the water sector:** by producing green hydrogen using wastewater. This is expected to provide new investment opportunity and economic value to a resource that is almost entirely unused.
- **Regulate hydrogen injection in the gas networks:** enabling the injection of hydrogen, and other renewable gases, into the natural gas transport and distribution networks has the advantage of reducing costs and barriers to the entry of hydrogen into the system, prevents gas assets from becoming idle in the future, and takes advantage of a system in operation that allows the immediate integration of hydrogen in the national energy system.
- **Support investment in hydrogen projects:** the Portuguese Government is planning to spend around 40 million euros to prepare and launch a Call to support

[103] Source: https://kig.pl/wp-content/uploads/2020/07/EN_H2_ENG.pdf

projects for the production and distribution of energy from renewable sources, which will include the hydrogen component.

- **Implement a mechanism to support the production of hydrogen:** by providing a clear and transparent support mechanism to the production of green hydrogen during the period 2020-2030. The support mechanism will provide support to cover the difference between the production cost of green hydrogen and the price of natural gas in the national market.

Markets and Demand

- **Set hydrogen incorporation targets** to ensure that the demand for hydrogen grows. This is done by setting targets for incorporating hydrogen in the various sectors of the economy, compatible with the ambition of the various sectors in the energy transition, with the current and future investment capacity and with the availability of technological solutions.
- **Decarbonise a national industry priority sector:** the decarbonisation of the industry will follow a prioritization based on a sector's importance in the national economy and its weight in greenhouse gases (GHG) emissions.
- **Decarbonise the transport sector:** Promote and support hydrogen, in addition to electricity and advanced biofuels, as a solution to achieve decarbonization in the road transport (heavy freight, urban logistics and passenger), in parallel with the dynamization of supply infrastructures.

D2. Australia

Australia published in 2019 a full hydrogen strategy[104], where it sets out the main actions that it undertakes to remove market barriers, build supply and demand and accelerate their cost-competitiveness. One of the key elements of Australia's hydrogen strategy is to create hydrogen hubs, ensure coordination among the Australian states and create training and upskilling arrangements for regulators.

Technology

- **Investments in hydrogen production technologies:** Australia is in the process of building three of the world's largest hydrogen electrolysers
- **Supporting research and pilots along the value chain** with a particular focus on:
    - Switching from current industrial hydrogen to clean hydrogen;

104 https://www.dcceew.gov.au/energy/publications/australias-national-hydrogen-strategy

- Exploring new opportunities for hydrogen such as clean ammonia exports, clean fertilizer exports and industrial use (heating, iron ore processing and steel making);
- Using hydrogen as back-up power supply;
- Enabling blending of hydrogen with natural gas;
- Optimizing hydrogen and electricity system interactions, for example through use of hydrogen for storage and dispatchable generation;
- Testing new technologies that reduce the cost of producing, transporting and using hydrogen;
- Developing cross-sector linkages; and
- Using water from sustainable sources.

Investment and Supply

- **Assessing the country's infrastructure needs:** Australia is aiming to complete by 2022 a full hydrogen infrastructure assessment. This assessment will consider hydrogen supply chain needs such as electricity and gas networks, water supply networks, refuelling stations, roads, rail and ports, while taking into account local community concerns and priorities. The assessment will be updated every five years, to reflect future needs.
- **Designing and developing an international guarantee of origin scheme** that will allow to track the hydrogen production technology used, the carbon emissions associated with the production and the production location.
- **Providing a clear taxation framework for hydrogen,** by committing to continue with the current revenue arrangements that apply to hydrogen, with the option to review them in the future.
- Proposing several **incentive schemes** for individuals and organisations to shift to low-carbon technologies and renewable energy, such as the Emission Reduction Fund and the Renewable Energy Target Scheme).
- **Working with bilateral partners** to promote trade and investment in hydrogen with the perspective to export hydrogen.
- **Creating training packages for entities operating along the hydrogen value chain.** For example, there is the plan to create training packages for Australian emergency services, based on the International Association for Hydrogen Safety and the U.S. Centre for Hydrogen Safety. Further training and guidelines will be created to ensure consistent information on the procedures related to the production, handling, transport and use of hydrogen.

- **Ensuring a 'hydrogen-ready' regulatory framework**. This will be done by reviewing the existing regulations to determine whether these can support hydrogen safety and hydrogen industry development and by seeking national regulatory consistency for new regulations.

Markets and Demand

- **Creating hydrogen hubs** as an early approach.
- Considering a role of hydrogen in supporting **Australian energy security** by 2025.
- Developing pilots and **trials of hydrogen used in gas distribution networks**.
- **Take an adaptive approach** to develop a vision of hydrogen as a clean and cost competitive fuel option for land and marine transport (in particular for heavy duty and long-range transport applications). This will be first implemented for transport tasks that do not require an extensive network of refuelling stations.
- **Raising awareness within the public** by providing an education programme that will present the particular benefits that hydrogen development can bring to regions as well as more general benefits such as economic growth, lower carbon emissions and reduced air pollution.

D3. Germany

Over the years, Germany has been transitioning its energy system to a more efficient one supplied mainly by renewable energy sources. To support the shift towards a low-carbon and nuclear-free energy system, Germany established the Energiewende framework in 2010. Moreover, the German Hydrogen Strategy,[105] published in 2020, sees hydrogen as an integral part of the energy transition, which will help decarbonise those hard-to-electrify sectors such as aviation, heavy duty transport and maritime transport. As of today, Germany is the largest European market for hydrogen, accounting for 21% of total European hydrogen production capacity and 22% of total demand.

Technology

- **Advancing research programmes in target applications**, such as aviation, maritime, international supply chains and sustainable hydrogen and derivative production in Germany and partner countries.
- **Improving Germany's and EU regulatory and policy framework for hydrogen R&D and production** – for instance via regulatory sand-boxes, tax/levy/surcharge

[105] https://www.bmwi.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.pdf?__blob=publicationFile&v=6

exemptions to production – in close discussion with business, science communities and civil society.

- Fostering target **education and vocational training** nationally and internationally.

Investment and Supply

- **Providing funding and creating favourable investment conditions along the value chain** in Germany and in the EU. For example, by providing capacity tenders, further developing the offshore wind deployment framework and evaluating re-use of existing gas infrastructure.
- Taking measures to **foster regional cooperation**:
- Establishing an **EU hydrogen company** developing international production capacities and infrastructure;[106]
- **Facilitating cross-border transport**
- **Strengthening and expanding international energy partnerships** integrating hydrogen (e.g., with North Africa)

Markets and Demand

- **Core measures targeting hard-to-electrify industry and transport**. The plan includes subsidies for steel and chemical substitution (via so-called carbon-contracts for differences) and fuel quotas in aviation (green hydrogen input quota for aviation fuels of 0.5% by 2026 rising to 2% by 2030).
- Foster international cooperation focussing on **standardisation** along the value chain (both on the supply and demand side) and creating **common green taxonomy**. Creating universal standards means that there are no adaptation costs to internationally trade hydrogen and its related infrastructure or appliances.

D4. Morocco

The Government of Morocco seeks to increase security of supply by reducing dependence on energy imports, including through the increase of renewable sources for electricity production. Moreover, Morocco created a National Hydrogen

[106] This is measure 33 of Germany's Hydrogen Strategy "*The establishment of a European hydrogen company to promote and develop joint international production capacities and infrastructure is being explored and will be progressed if there is sufficient European backing*." We have not identified EU announcements building on this recommendation.

Commission in 2019 to develop a road map for deploying green hydrogen strategy, which was published in 2021.[107]

Technology

- Facilitating cost reduction along the PtX value chain.
- Setting up a Moroccan and international cluster favouring industry-science-government coordination.
- Defining the relevant measures for local content favouring joint-ventures and coordination between industry-training-academia.

Investment and Supply

- **Setting-up industry cluster** and develop a related infrastructure masterplan.
- **Securing financing** to develop the PtX industry. For instance, favouring international agreements and adhesion to international financing tools.

Markets and Demand

- **Creating the conditions for exporting PtX products** from Morocco, including favouring international agreement on technical standards.
- **Assessing in detail a storage plan** for the electricity sector.
- **Developing domestic markets**, for instance, providing subsidies – in the short term – or establishing carbon taxes in the long-term encouraging industries and heavy transport to adopt clean fuels.

[107] https://www.mem.gov.ma/Pages/actualite.aspx?act=278

Annex E. Green hydrogen impact in gross value added and jobs creation

Establishing a green hydrogen sector has a significant impact on the economy by contributing to an appropriate green engine. Energy supply is suitable to enhance growth when it is sustainable, secure and affordable. We discuss how green hydrogen contributes to this in section 6.1.

Implementing the Northern Irish vision for green hydrogen involves creating a domestic green hydrogen production industry and setting out related infrastructure to fuel various sectors. These include mobility and blending in the short term, and the expansion of uses for mobility, industry and possibly heating in the long term. Inter-seasonal large-scale storage for the power sector may also materialise. The Northern Irish vision also involves accelerating innovation to participate in the global hydrogen market as a technology provider.

Realising the vision involves introducing new economic activities that will directly contribute to Northern Ireland's Gross Value Added (GVA) and jobs. We select sectors that experience additional economic activity in terms of gross value added and job creation and draw insights on the green hydrogen sector from historical data on referent sectors. Our analysis refers to both UK-wide and Northern Irish specific referents. Figure 42 summarises this approach[108]. Our approach follows the methodology of BEIS[109] and Element Energy.[110]

Figure 42. Summary approach to assess potential job creation linked to a hydrogen economy

[108] Element Energy (November 2019) Unlocking Jobs and GVA whilst reducing emissions in the UK.

[109] BEIS (October 2019) Energy Innovation Needs Assessment: Overview Report.

[110] Element Energy (November 2019) Unlocking Jobs and GVA whilst reducing emissions in the UK.

Mapping sectors

Our analysis starts by identifying the sectors that the Northern Ireland green hydrogen vision would stimulate (see Figure 43). Activities could receive a direct or indirect stimulus, as follows:

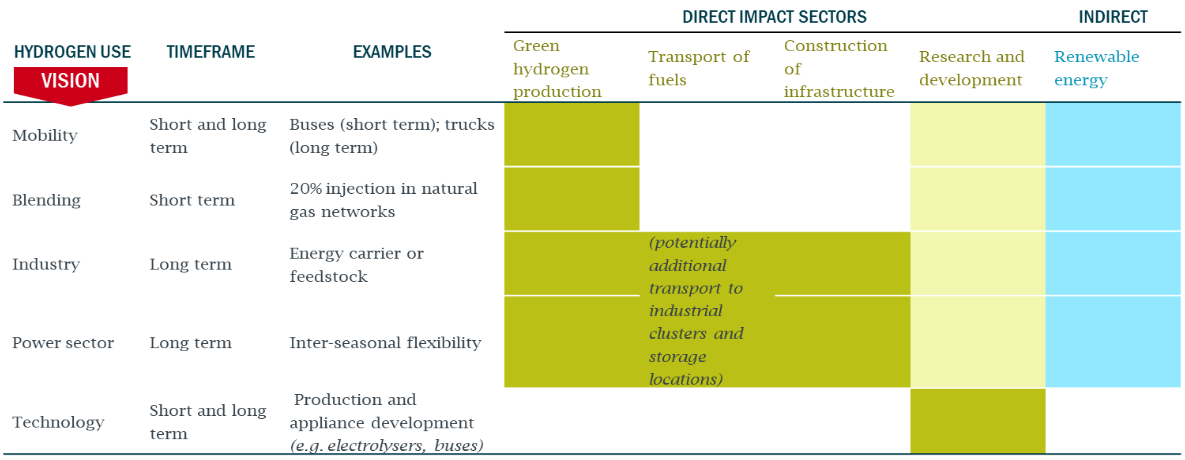
Activities with a direct stimulus:

- Green hydrogen production: converting (renewably-generated) electricity to hydrogen.
- In the case of the use of hydrogen for inter-seasonal flexibility, hydrogen will be stored for example in salt caverns and converted back to electricity.[111]
- Hydrogen transport, for example to storage locations, or to industrial clusters.
- Constructing the infrastructure required to distribute and store hydrogen.
- Developing hydrogen adaptation technologies through research and development.

Indirect impact comes from higher up the supply chain, most notable renewable energy generation. Involved activities include, for instance, wind turbine installation and operation.

We assume no wider impact in other parts of the supply chain, for example producing the capital goods required for green hydrogen production such as electrolysers, because these are more likely to be imported.

Figure 43. Identifying hydrogen economy impact sectors



[111] There may be additional activity associated with the operation of storage locations such as salt caverns for inter-seasonal flexibility, however we assume this to be minimal.

To select referent sectors, we employ the Standard Industrial Classification (SIC), which categorises firms according to their primary activity, to map the sectors identified as directly or indirectly impacted in UK-wide and Northern Irish official statistics (see Table 6 and Table 7). We jointly consider both statistics, and not only Northern Irish specific information, because UK-level GVA and turnover data is available at a more detailed industry level.[112] The less detailed data from Northern Ireland may be less accurate in capturing differences between the sectors under consideration. In considering both sources, we present the results as ranges from minimum-maximum estimates to capture the uncertainty in some estimates of smaller sectors.

112 GVA and turnover data are taken from the Annual Business Survey 2019.
Employment data from Business Register and Employment Survey 2019 – Northern Ireland (NISRA); and Business Register and Employment Survey 2019 – Great Britain (ONS via nomis.web).

Table 6. Mapping to industries from standard industrial classification: UK

Impact sector:	Mapped sector name from SIC:	SIC Section:	SIC Code:
Green hydrogen production/Transport of fuels	Manufacture of gas; distribution of gaseous fuels through mains	D	35.20
Transport of fuels	Transport via pipeline	H	49.50
Construction of infrastructure	Construction of utility projects	F	42.20
Construction of infrastructure/R&D	Engineering activities and related technical consultancy	M	71.12
Research and development	Research and experimental development on natural sciences and engineering	M	72.10
Renewable energy production	Electric power generation, transmission and distribution	D	35.10

Source: Annual Business Survey, 2019

Table 7. Mapping to industries from standard industrial classification: Northern Ireland

Impact sector:	Mapped sector name from SIC:	SIC Section:
Green hydrogen production/Transport of fuels/Renewable energy production	Electricity, gas, steam and air conditioning supply	D
Transport of fuels	Land transport and transport via pipelines	H
Construction of infrastructure	Civil engineering	F
Research and development	Scientific research and development	M

Source: Annual Business Survey, 2019

Drawing lessons from referents

We review historical ratios of turnover/employment and turnover/GVA[113] to draw lessons from the selected sectors. These indicators are an estimate for each sector of how many additional jobs and how much additional GVA may be generated for a given level of additional turnover.

It should be noted that in all cases the estimates are not additional and cannot be interpreted as net impacts, because we do not take account of potential displacement, substitution and leakage effects. For example, the extra employment/GVA generated in renewable sectors could to some extent be offset by reductions in employment/GVA in traditional power generating sectors which will be displaced, so that there may be no overall net employment or net GVA impact.

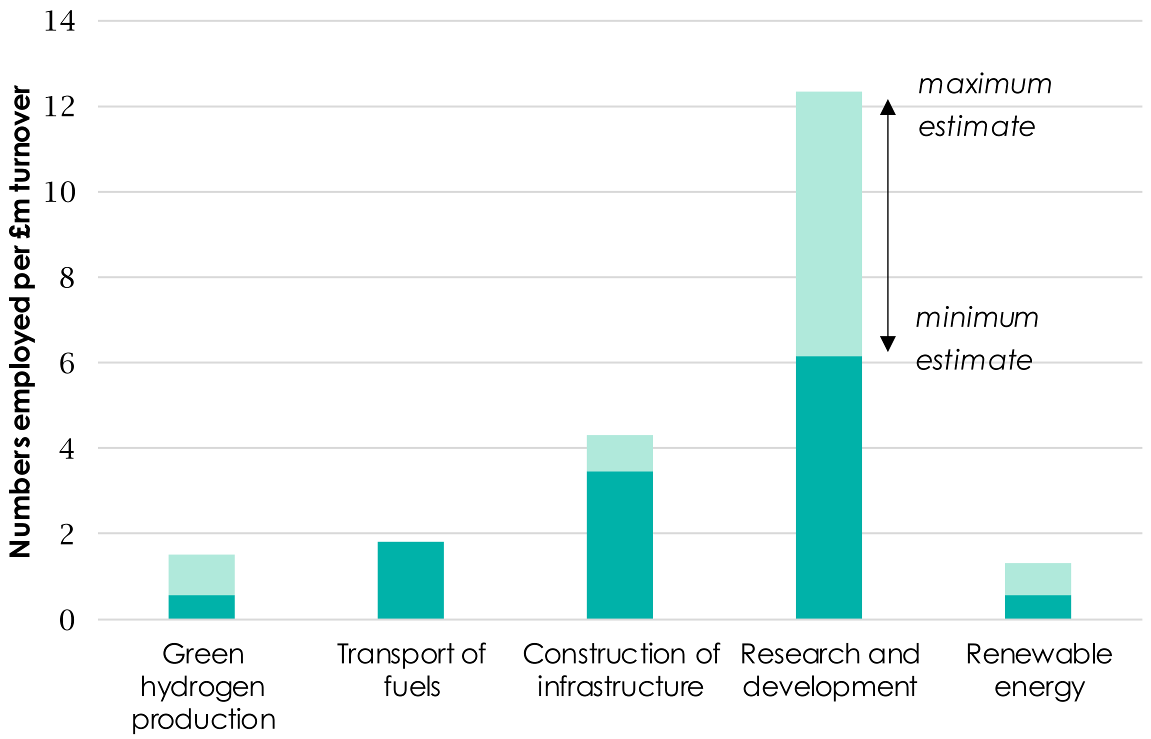
The indicative results of this analysis for employment are presented in Section 6.1. below we present the indicative results for GVA impacts.

Gross value added intensity of referent sectors

In order to draw lessons from these sectors about the potential implications on GVA, we assess their GVA intensity measured as the Gross Value Added generated (£) per £ of turnover. This indicates the potential impact on GVA for a given increased level of activity/turnover in the relevant sectors.

[113] Note both indicators refer to turnover. We consider the activity generated in each sector as an additional market opportunity which can be measured in terms of turnover, defined as the total value of sales. Assuming a viable industry without excess profits, total turnover for one industry is likely to be in line with the cost incurred by that industry, meaning that total turnover can be a proxy for total cost, a measure of inputs.

Figure 44. Gross value added intensity in reference sectors



Source: Annual Business Survey 2019; Business Register and Employment Survey 2019 - Northern Ireland (NISRA); Business Register and Employment Survey 2019 – Great Britain (ONS via nomis.web); Frontier calculations

Notes:

(1) Estimate ranges are derived from both UK and Northern Ireland referent intensity data

(2) In the transport of fuels sector, we only have one estimate taken from UK-level data: the Northern Ireland-based estimate was not judged to be representative as the industry category includes passenger and freight transport.

(3) The wide estimate range for the Research and Development industry is driven by large differences in the estimates for the UK and for Northern Ireland (NI estimates are higher for both GVA and employment ratios). This could be representing a higher GVA and employment intensity in NI or could be a feature of a smaller sample size because of a smaller overall industry in NI. We present both estimates for reference.

Annex F. Carbon tax adjustment mechanism

In its Fit-for-55 package[114] the EU proposes the introduction of a Carbon Border Adjustment Mechanism (CBAM). This is a border tax that applies only to imports of selected products and it's based on their carbon-intensity. The objective of the Carbon Border Adjustment Mechanism is to prevent that the emissions reduction efforts of the EU are offset by increasing emissions outside its borders through relocation of production to non-EU countries or increased imports of carbon-intensive products (the so called "carbon leakage").[115]

The level of taxation on products will be based on EU ETS allowances. In particular, importers of carbon-intense products have to purchase and surrender a certificate for each tonne of CO_2 produced. The price of the CBAM-certificate will be defined based on weekly average auction prices in the EU ETS.

The regulation will initially apply on electricity and products produced in four energy-intensive industries: cement, iron and steel, aluminium, fertilisers. These are sectors that the European Commission recognises at risk of carbon leakage, which is currently managed through the granting of free allowances.[116]

The proposal envisages a transitional phase from 2023 until 2025. In this period the declarants will have to report the embedded emissions in goods important, but the taxation will not be in place yet. Moreover, importers may not have already in place systems to estimate the CO_2e emissions produced. For this reason, in the transitional phase, the value of embedded emissions will first be assessed based on a default emission intensity defined by the Commission. Importers can provide more detailed information on the production processes of imported products to national authorities to define the CBAM obligation more accurately.

[114] The Fit for 55 package is a set of proposals to revise and update EU legislation and to put in place new initiatives with the aim of ensuring that EU policies are in line with the climate goals agreed by the Council and the European Parliament. Source: https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/

[115] European Commission (2021) *Proposal for a regulation of the European Parliament and of the Council establishing a carbon border adjustment mechanism*.

[116] Under this mechanism industrial participants in the ETS are provided with free allowances, which they can sell or use to cover their direct emissions.

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