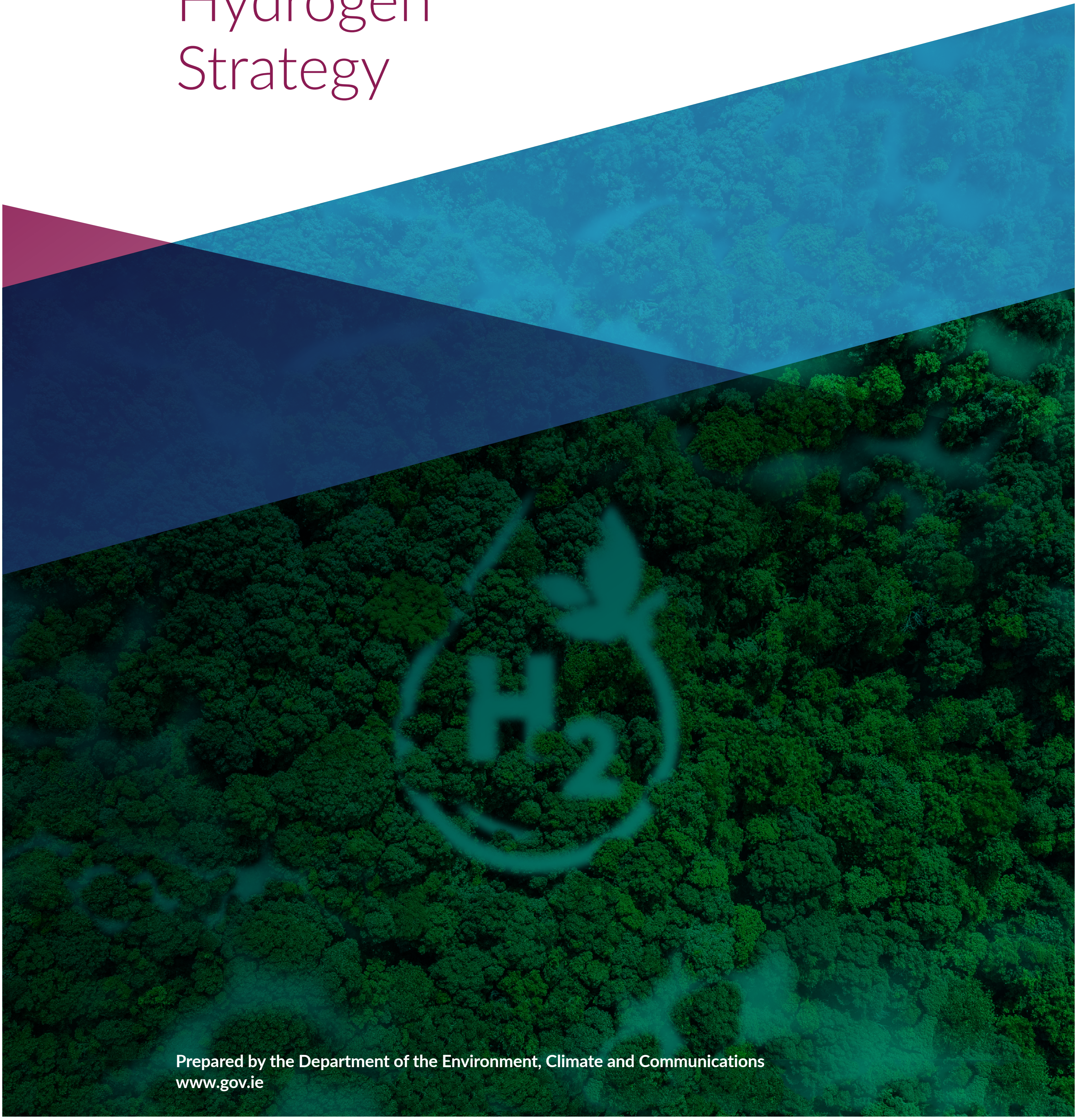
Rialtas na hÉireann
Government of Ireland

National Hydrogen Strategy



Prepared by the Department of the Environment, Climate and Communications
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Minister's Foreword

Climate action is the most pressing long-term global challenge of our time and is a significant priority for the Government of Ireland. Through our strengthened climate legislation, the 2020 Programme for Government, and our annually-updated Climate Action Plan, we have set ourselves the ambition of halving Ireland's greenhouse gas emissions by the end of the decade and becoming carbon neutral by 2050. We are determined that Ireland will play its full part in EU and global efforts to stop climate change and, in so doing, harness the opportunities and rewards that will come from moving quickly to a low-carbon society.

Decarbonised gases like renewable hydrogen will have a key role to play in this transition and should become part of our future energy system. We have a distance to travel, but together we can and will pursue the best interests of people through responsible, transformative climate action. We must take better care of our planet. This generation must be the one to pass on our planet in a better condition than we inherited.

Over the past number of years, I've been closely following the rapid development of renewable hydrogen technology globally. It is a technology that offers incredible opportunities for Ireland. It provides the potential for long-duration energy storage, dispatchable renewable electricity, the decarbonisation of some parts of high-temperature processing, as well as a potential export market opportunity. Ireland has the natural resources to become a world leader in the production of green energy. Our wind resources are amongst the best in the world. Hydrogen represents one of the best ways of capturing these resources and specifically our capacity to produce renewable hydrogen from our excess energy. Realising the full potential of this massive resource will be a major opportunity for Ireland.

This strategy sets out our vision for how hydrogen will be produced and used in Ireland, as well as what needs to be done to enable the development of Ireland's hydrogen sector, providing greater certainty on the role that hydrogen will play in the Irish energy system and delivering an important first step in the establishment of a significant hydrogen industry in Ireland. Hydrogen provides us with an incredible opportunity in Ireland, but its use must be targeted to the uses where it will deliver the greatest benefits. We must not become distracted by the possibility to deploying hydrogen technologies where direct electrification would deliver a better outcome. If it is not efficient, if it is not the best use, and if it is not in line with our net zero plans, then we will not be doing it. We must collectively focus on the things that hydrogen is better than other solutions. We must focus on the real markets, where hydrogen will end up as the most advantageous solution.

It is vital that Ireland realises the full potential of renewable hydrogen to decarbonise our economy and energy systems, and the publication of this strategy is an important first step to achieving this goal. While this is only the beginning, it sets out the important initial building blocks upon which the sector can grow, allowing Ireland to explore and harness the opportunities offered by a green hydrogen economy.

Eamon Ryan TD
Minister for the Environment, Climate and Communications and Transport

Executive Summary

Policy Drivers

The three primary strategic reasons for developing an indigenous hydrogen sector in Ireland are decarbonisation, energy security and developing industrial opportunities.

1. **Decarbonising our economy**

   Ireland is on a pathway to net-zero emissions by no later than 2050. Delivering on this legally binding target will require no less than a transformational change of our entire energy and economic ecosystem. Indigenously produced renewable hydrogen can play a significant role in enabling this transition as it does not emit carbon dioxide (CO2) when used. Renewable hydrogen (often referred to as "green hydrogen") has the potential to become a zero-carbon substitute for fossil fuels in many sectors of our economy considered hard to decarbonise, where other solutions such as direct electrification are not feasible or cost effective. This is the primary reason for delivering the National Hydrogen Strategy.

2. **Enhancing our energy security**

   Hydrogen can also play an important role in ensuring the security of Ireland's energy supplies into the future. Ireland imported 77% of its energy supply in 2021, up from 72% in 2020[1]. However, due to our location in the Atlantic, Ireland's coast is one of the most energy productive in Europe and with a sea area approximately seven times the size of our landmass, Ireland has one of the best offshore renewable energy resources in the world. Harnessing this renewable energy into the production of renewable hydrogen provides a significant opportunity for Ireland to reduce our reliance on imported fossil fuels and potentially even achieve energy independence. Given its high energy density as a gaseous fuel, hydrogen is also well suited to support the development of large-scale seasonal storage applications, helping to manage the variability of renewable energy sources such as wind or solar, or the seasonality of demand patterns across the year. Fossil fuels are used as a backup to renewables today, but renewable hydrogen can offer a zero-carbon alternative in the future. This was recognised in the National Energy Security Framework[2], which called for the development of a National Hydrogen Strategy to support Ireland's energy security into the future.

3. **Creating industrial and export market opportunities**

   Whilst supporting decarbonisation and energy security are the foremost goals of delivering the National Hydrogen Strategy, there are also potential industrial and export market opportunities that may arise from its development. Given our vast renewable resources, Ireland has the potential to produce renewable hydrogen in excess of our own needs in the long-term. With many countries across Europe having identified a long-term need for renewable and low carbon hydrogen imports to meet their own decarbonisation needs, Ireland could be well placed to supply these markets. Developing an export market for renewable hydrogen could deliver many benefits for the development of hydrogen domestically. An export market could help to deliver the necessary economies of scale needed to reduce production costs, allowing hydrogen to become competitive and strengthening the business case for large scale infrastructure such as a national hydrogen network to be developed. An export market could also deliver economic growth and the creation of many high skilled jobs in the renewable energy sector across Ireland. In recognition of this fact, this strategy will also set out actions to explore these opportunities further.

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1 https://www.seai.ie/data-and-insights/seai-statistics/key-publications/national-energy-balance/#comp00006023933e000000bbbe3751

2 86cb99f5-58e3-4821-bc4c-e1bb1fa706fb.pdf (www.gov.ie)

Purpose of the National Hydrogen Strategy

Whilst renewable hydrogen can offer many opportunities for Ireland, it is still very much a nascent technology with great uncertainty on the future costs, potential end-uses and the infrastructure, skills and supply chains needed to deliver on it. The National Hydrogen Strategy aims to reduce some of this uncertainty by providing the long-term strategic vision of what role hydrogen will play in our future economy, which will help to reduce commercial risk and ultimately help to drive investment from the private sector.

In the shorter term, this strategy sets out several actions to be delivered over the coming years to enable the development of the hydrogen sector in Ireland. These actions aim to remove any barriers which could inhibit early hydrogen projects from progressing today and to enhance our knowledge through targeted research and innovation across the value chain. As the sector develops, further action will be required to build on these early actions. The Interdepartmental Hydrogen Working Group will work to monitor the delivery of these actions and the identification of further measures to support future phases as the sector develops.[3]

The National Hydrogen Strategy is our first major policy statement on renewable hydrogen in Ireland and is an important milestone in the development of the sector.

Key Questions Addressed Through the National Hydrogen Strategy

The National Hydrogen Strategy assesses both the long-term needs and short-term actions to enable hydrogen to develop across the entire value chain, aiming to address the following:

1. How will Ireland kickstart and scale up production of renewable hydrogen?
2. Which end-use sectors will hydrogen be targeted towards? From when are these end-use sectors anticipated to be supplied with hydrogen? What are the quantities that are likely to be needed?
3. What infrastructure does Ireland need to support the development of the hydrogen sector (including transportation and storage)? How should this infrastructure be developed?
4. How will we ensure that the necessary safety, environmental and market rules are in place to enable the sector to grow in a safe and sustainable way?
5. How can we create the conditions that will support continued technological growth and innovation?

[3] The Interdepartmental Hydrogen Working Group was established in 2020 to enable greater collaboration and coordination across the departments and its agencies in respect to research and policy development of hydrogen in Ireland. Its members include the Department of the Environment Climate and Communications, the Department of the Taoiseach, Department of Transport, Department of Enterprise, Trade and Employment, the Sustainable Energy Authority of Ireland, the Commission for Regulation of Utilities, EirGrid (the Electricity Transmission System Operator), Gas Networks Ireland (the Gas Transmission System Operator) and the National Standards Authority of Ireland.

Main Takeaways from the National Hydrogen Strategy

Kickstarting Production	• Ireland will prioritise the scale up and production of renewable hydrogen. • Prior to 2030, hydrogen will be produced from grid connected electrolysis from surplus renewables. This will initially be needed to meet EU targets in specific end-use sectors such as transport and will likely be used in the power system. The operating models for these should be beneficial to the electricity system and sufficient grid infrastructure is needed to facilitate this. • A 2 GW target of offshore wind, for the production of renewable hydrogen, to be in development by 2030, will help to provide greater certainty for investors and create the volumes needed to scale up the sector. • Ireland has one of the best offshore wind resources globally and has the potential to develop a decarbonised industrial opportunity in proximity to this resource, and to become a net exporter of renewable hydrogen in the longer term.
Clarity on End Uses	• The deployment of renewable hydrogen in Ireland will focus on hard-to-decarbonise sectors where energy efficiency and direct electrification are not feasible or cost-effective solutions. • Heavy duty transport applications where there are binding EU targets for 2030 are anticipated to be the first end use sectors to develop, followed closely by industry and flexible power generation. • Aviation and maritime are expected to be large high priority end-users but these sectors will take longer to develop. • Indicative projections estimate that Ireland's domestic hydrogen energy demand needs could equate to between 4.6 and 39 TWh by 2050. When including non-domestic energy needs such as International Aviation and Shipping, these values could rise to between 19.8 to 74.6 TWh. This wide range demonstrates the significant uncertainties which exist due to the nascent nature of the market. • Future work is needed to better understand the needs of potential end-use sectors, the volumes of renewable hydrogen required within these sectors and the role that renewable hydrogen can play in an integrated net zero energy
Enabling Infrastructure	• Initial hydrogen applications are likely to utilise compressed tankering solutions. As production expands, hydrogen pipelines are envisioned to become the dominant transportation option. • Hydrogen infrastructure is expected to roll out initially across several regional clusters where production, high priority demand uses and large-scale storage are co-located. • The expansion and linking of these clusters into a national hydrogen network will be key to creating a liquid mature hydrogen market. Where feasible, repurposing existing natural gas pipeline infrastructure to hydrogen is favourable. • Work to date has shown promising results in terms of the technical capability of the gas network to transport hydrogen blends up to 100%. More work is needed to better understand the costs, phasing of transition and potential impacts for existing network users. • Long duration storage is essential to the future cost competitiveness and price resilience of hydrogen. Geological storage solutions will be needed to support this. • Networks and storage infrastructure, as well as interconnection import/export routes, will play a key role in ensuring security and price resilience of supply. • Commercial ports will play an important role in facilitating the establishment of a hydrogen economy. • Long-term integrated planning is essential to identify the long-term infrastructure needs to deliver an integrated net zero energy system.

continued

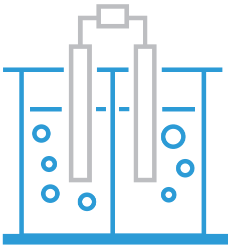
Safety and Regulation	• Hydrogen safety is essential, and early focus is needed to develop a safety roadmap to delivering the necessary safety frameworks and regulatory regimes across the entire hydrogen value chain. • The EU Hydrogen and Decarbonised Gas Package sets out the regulatory market rules for scaling up hydrogen and the development of dedicated hydrogen infrastructures. Ireland should adopt the outcomes of this in a timely manner. • Renewable and low carbon hydrogen will be defined in line with EU regulations, and a certification scheme should be established to reflect these definitions, providing certainty to end users as to the origin and sustainability of their hydrogen. • Considerations around hydrogen leakage and NOx emissions are already being assessed at European level. Future standards may be developed to mitigate these risks and adopted at a national level. • There are several gaps in terms of regulations, licensing and permitting across the entire hydrogen value chain. A full review is needed to identify these gaps and ultimately implement the required changes to alleviate them.
Enabling Innovation and Skills	• Renewable hydrogen is still a nascent technology. Global research and innovation over the coming years will be essential to future competitiveness and scale up. • Climate research is a strategic priority of Ireland's research and innovation strategy, as set out in Impact 2030: Ireland's Research and Innovation Strategy • Ireland has a proven track record in supporting research and innovation, as well as delivering results. • Targeted, short-term research needs have been identified throughout the National Hydrogen Strategy which will be essential to ensuring future informed policy making in the space. • The European Union has invested heavily in supporting hydrogen related research and development initiatives. Leveraging these resources and applying them to Ireland will be important. • Further work to build strategic international partnerships in the fields of renewable hydrogen development will be an important enabler. • Further work is needed to better determine the skills required, short falls and the opportunities for employment in Ireland in respect to renewable hydrogen.

Ireland's Strategic Hydrogen Development Timeline Roadmap

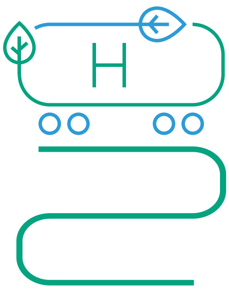
Our strategic hydrogen development timeline roadmap below sets out our vision for how we expect the hydrogen economy to develop and scale up over the coming decades, across the entire value chain. It can act as a simple guide to show when different components of the hydrogen sector are anticipated to be needed by as the sector ramps up during the transition to net zero.

Along with the list of actions published as part of this National Hydrogen Strategy, it will help to provide clarity on the sequencing of future actions needed and guide our work over the coming months and years.

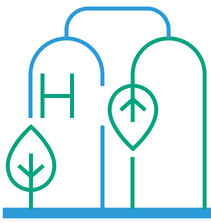
Table 1: Ireland's strategic hydrogen development timeline roadmap



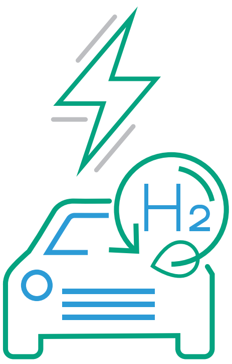
Production	2023-28	2028-33	2033-38	2038-50
Renewable hydrogen produced from curtailed grid electricity or onshore renewables where available	Large scale deployment envisioned	Large scale deployment envisioned	Large scale deployment envisioned	Large scale deployment envisioned
Hydrogen blends across the interconnectors	Small number of niche applications	Small number of niche applications	Small number of niche applications	Unlikely to exist
Renewable hydrogen from Offshore Wind	Unlikely to exist	Small number of niche applications	Large scale deployment envisioned	Large scale deployment envisioned



Transportation	2023-28	2028-33	2033-38	2038-50
Trucked (non-pipeline) or onsite use	Large scale deployment envisioned	Large scale deployment envisioned	Small number of niche applications	Small number of niche applications
Network blending	Small number of niche applications	Small number of niche applications	Unlikely to exist	Unlikely to exist
Local networks/clusters	Unlikely to exist	Large scale deployment envisioned	Large scale deployment envisioned	Small number of niche applications
National hydrogen network	Unlikely to exist	Unlikely to exist	Small number of niche applications	Large scale deployment envisioned
Import/Export Routes established	Unlikely to exist	Unlikely to exist	Small number of niche applications	Large scale deployment envisioned



Storage	2023-28	2028-33	2033-38	2038-50
Network blending	Small number of niche applications	Small number of niche applications	Unlikely to exist	Unlikely to exist
Small scale storage applications	Large scale deployment envisioned	Large scale deployment envisioned	Small number of niche applications	Small number of niche applications
Large scale storage solutions of geological scale	Unlikely to exist	Small number of niche applications	Large scale deployment envisioned	Large scale deployment envisioned



End Uses	2023-28	2028-33	2033-38	2038-50
Existing Large Energy Users on gas network using GOs	Small number of niche applications	Small number of niche applications	Unlikely to exist	Unlikely to exist
Heavy Land Transport	Small number of niche applications	Large scale deployment envisioned	Large scale deployment envisioned	Small number of niche applications
Power Generation	Unlikely to exist	Small number of niche applications	Large scale deployment envisioned	Large scale deployment envisioned
Industrial Heating	Unlikely to exist	Small number of niche applications	Large scale deployment envisioned	Large scale deployment envisioned
Aviation and Shipping	Unlikely to exist	Unlikely to exist	Small number of niche applications	Large scale deployment envisioned
Exports	Unlikely to exist	Unlikely to exist	Small number of niche applications	Large scale deployment envisioned

Unlikely to exist | Small number of niche applications | Large scale deployment envisioned

Implementing the National Hydrogen Strategy

The Strategy sets out the long-term strategic vision of what role hydrogen will play in our future economy and what needs to be done in the coming years to enable the development of the hydrogen sector in Ireland. This will be accomplished by delivering on the key actions set out in the Strategy, detailed below in Table 2, using future iterations of the Climate Action Plan and the Interdepartmental Hydrogen Working Group to underpin and coordinate delivery.

This Strategy will be regularly reviewed by the Interdepartmental Hydrogen Working Group to ensure it aligns with the needs of the hydrogen sector as it develops over time, including any updates to the Strategy (including additional actions) which may be necessary.

Table 2: List of actions to be delivered through the National Hydrogen Strategy

#	Action	Timeline
1	Develop and publish data sets showing the likely locations, volumes, and load profile of surplus renewables on our electricity grid out to 2030	2023-24
2	Establish an early hydrogen innovation fund to provide co-funding supports for demonstration projects across the hydrogen value chain	2023-27
3	Adopt EU standards for renewable and low carbon hydrogen and develop a national certification scheme to provide clarity to end users as to the origin and sustainability of their hydrogen	2023-25
4	Develop the commercial business models to support the scale up and development of renewable hydrogen, targeting surplus renewable grid electricity pre-2030 and an initial 2 GW of offshore wind from 2030	2023-30
5	Develop a roadmap to bring net zero dispatchable power solutions to market by 2030, to support the delivery of a near net zero power system by 2035	2024-26
6	Undertake further work to assess the role that integrated energy parks could play in our future energy system, including their potential benefits and the possible barriers (market, legal or other) that may exist	2023-25
7	Publish the draft National Policy Framework on Alternative Fuels Infrastructure, and support the roll-out of hydrogen powered heavy duty vehicles and refuelling infrastructure in line with EU requirements set out in the recast Renewable Energy Directive and Alternative Fuel Infrastructure Regulation	2024-30
8	Through the development of the National Industrial Strategy for Offshore Wind, assess the feasible potential for end uses such as eFuels, decarbonised manufacturing and export of Hydrogen and its derivatives.	2024-26
9	Undertake further work to determine the quantities and profile of zero carbon long duration energy storage needed out to 2050, and develop a roadmap as to how it can be delivered	2024-26
10	Undertake a review of the existing licensing and regulatory regimes relevant to the geological storage of hydrogen, and progress the necessary legislative changes and development of regulatory regimes to facilitate future prospecting and development of underground hydrogen storage solutions	2024-28
11	Continue work to prove the technical capabilities of the gas network to transport hydrogen through the network and closely work with the network operators in neighbouring jurisdictions in respect to interoperability between the networks	2023-28

continued

#	Action *(continued)*	Timeline
12	Develop a plan for transitioning the gas network to hydrogen overtime, taking due consideration of: a. plans to develop a biomethane sector in Ireland, b. the prioritisation of end uses set out in the National Hydrogen Strategy and their likely locations where known, c. the need to maintain energy security through the transition, d. how existing end users can transition from natural gas to hydrogen, or to alternative energy solutions such as electric heating, e. the potential use of hydrogen blends during a transition phase, the costs associated and how the transition from blending can occur The plan should look to identify where the network can be repurposed, or where new pipelines may be required and provide detailed costings and a programme of works	2023-26
13	Progress work to identify and support the development of strategic hydrogen clusters	2024-26
14	Commence a review of current approaches to energy systems planning and make recommendations to support a more integrated long-term approach to planning across the network operators including electricity, natural gas, hydrogen, and water	2024-26
15	Establish a working group with the relevant regulators, government, and industry representatives to develop a safety roadmap to delivering the necessary safety frameworks and regulatory regimes across the entire hydrogen value chain	2024-26
16	Adopt the hydrogen and decarbonised gases market package into legislation once approved by the EU institutions	2024-27
17	Undertake a review across the entire hydrogen value chain to identify any other gaps within our spatial planning, environmental permitting, and licensing regimes	2024-26
18	Engage with Ireland's research sector to ensure sufficient focus is given to renewable hydrogen development and work to commission relevant research to help close the knowledge gaps identified throughout the National Hydrogen Strategy	2024 – ongoing
19	Continue to engage in EU hydrogen related initiatives and develop cooperation in the fields of renewable hydrogen development with neighbouring jurisdictions and international partners	2024-ongoing
20	Through the expert advisory group on skills established under the Offshore Wind Delivery Task force, continue to assess, and support the future skill needs of the offshore wind and renewable hydrogen sectors	2023-ongoing
21	Review and update the Terms of Reference of the Interdepartmental Hydrogen Working Group to recognise its role in terms of oversight and implementation of the National Hydrogen Strategy	2023-24

1 The Renewable Hydrogen Opportunity For Ireland

Key Messages

- Decarbonised gases like hydrogen should be a critical component of Ireland's net zero integrated energy system.
- Its use should be targeted towards "hard to decarbonise" sectors.
- Ireland has a strategic opportunity to produce renewable hydrogen at scale, with potential to produce more than our own indigenous needs.
- The starting point is different in Ireland as limited industrial demand for immediate use exists today, compared to other jurisdictions.
- The establishment of a renewable hydrogen industry in Ireland can play an important role in Ireland's future energy security, supporting continued economic growth, opening potential new markets, including exports, and domestic industrial opportunities.

The Climate Action and Low Carbon Development (Amendment) Act 2021[4] has put Ireland on a legally binding path to net-zero emissions by no later than 2050, and to a 51% reduction in emissions by 2030. To achieve this, the transition must be made to a climate resilient, biodiversity-rich, environmentally sustainable, and climate-neutral economy. Realising these ambitions will require a coordinated effort across Ireland and every economic sector will be involved. It requires no less than a national transformation over the coming years in how we work, travel, heat our homes, source our energy, and use our land.

Indigenously produced renewable hydrogen offers an incredible opportunity for Ireland and could play a significant role in enabling this transition to a net zero economy. As it does not emit carbon dioxide (CO_2) when used, renewable hydrogen (often referred to as "green hydrogen") has the potential to become a zero-carbon substitute for fossil fuels in many hard to decarbonise sectors. Specifically, in the coming years renewable hydrogen is envisioned to play an important role in decarbonising industrial processes, long duration energy storage of renewable energy, as a zero-emission source of dispatchable flexible electricity and as a transport fuel in sectors such as heavy goods transport, maritime and aviation.

However, it is also likely to be a relatively expensive energy carrier and less efficient than direct use of the renewable electricity used to produce it, with energy losses occurring through the conversion process. It is important to clearly set out that for many end-use sectors there will be alternative decarbonisation solutions, such as direct electrification, that may offer a cheaper and more energy efficient option. There will also be some end-use sectors where decarbonised gases like hydrogen are the only viable solution. In this respect, Ireland's decarbonisation pathway will follow the principles of the EU Energy Systems Integration strategy, which promotes greater integration across the energy carriers, a focus on enhancing energy efficiency, greater direct electrification, and direct use of renewables, as well as the use of renewable and low carbon fuels, such as hydrogen, targeted towards sectors considered hard to decarbonise[5]. The priority end-uses for renewable hydrogen in the Irish energy system are discussed in Section 3.

[4] Climate Action and Low Carbon Development (Amendment) Act 2021 (irishstatutebook.ie)
[5] EU Energy System Integration Strategy (europa.eu)

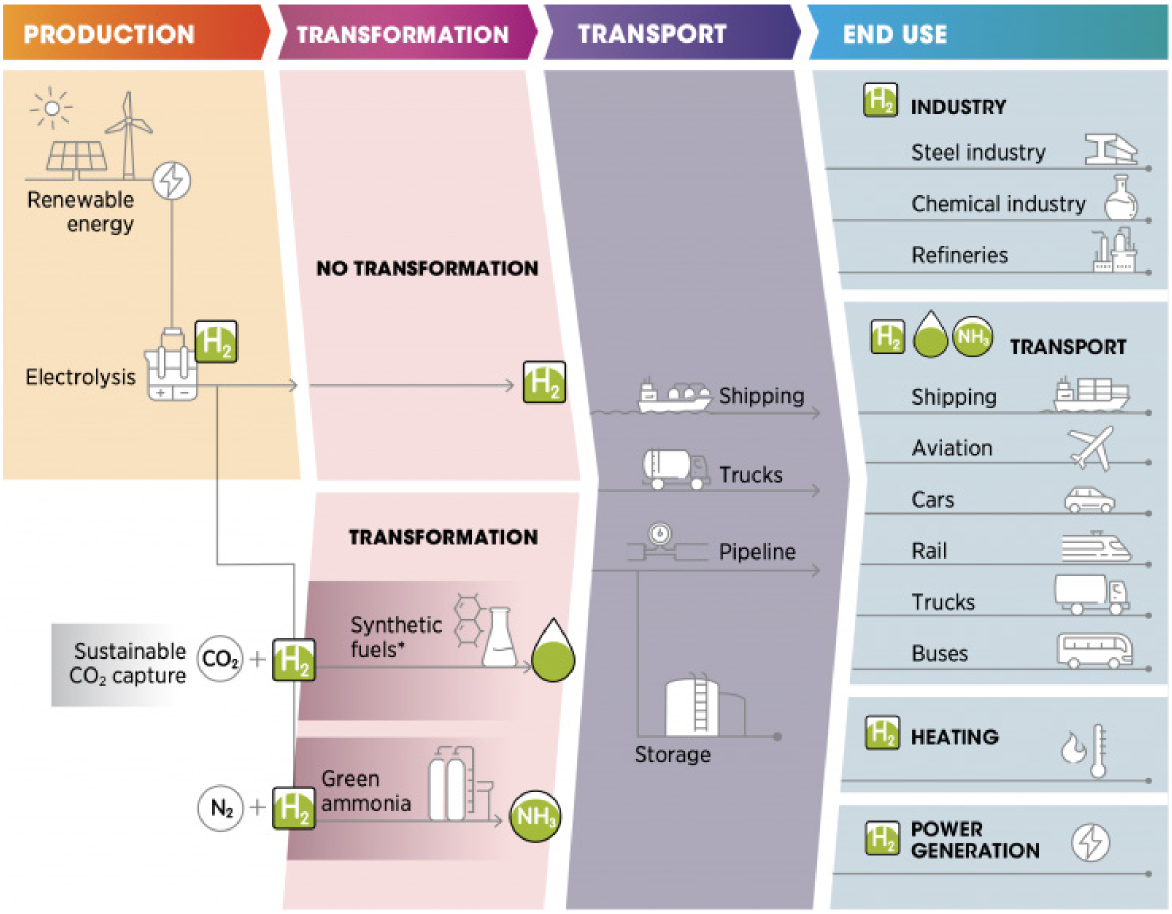


Figure 1: The Renewable Hydrogen Value Chain (Source: IRENA[6])

Hydrogen accounts for less than 2% of the EU's current energy consumption and is mostly used as feedstock in industrial processes, notably oil refining, ammonia, and methanol production. Most hydrogen used today is fossil fuel based "grey" hydrogen, meaning it has been produced from hydrocarbons without any abatement of the carbon emitted in the production process, making it a carbon intensive and non-sustainable form of production. However, many countries are now seeing the need to rapidly decarbonise and increase their hydrogen supply to deliver a net zero energy system. The EU Hydrogen Strategy, published in 2020, envisions that 13-14% of EU energy consumption will be from hydrogen by 2050[7], while some European countries such as the United Kingdom and the Netherlands are expecting hydrogen to make up between 20-35% and 30-50% of their final energy demands respectively[8, 9]. Further analysis is needed to quantify the long-term demand projections for hydrogen demand in Ireland, although some indicative sectoral volume ranges are discussed later in Section 3.

Ireland has a considerable offshore and onshore renewable resource and realising the full potential of this massive resource will be a major opportunity for renewable hydrogen production. With a sea area approximately seven times the size of our landmass, Ireland has one of the best offshore

6 Green hydrogen supply: A guide to policy making (irena.org)
7 EUR-Lex – 52020DC0301 – EN – EUR-Lex (europa.eu
8 UK Hydrogen Strategy (publishing.service.gov.uk)
9 Government Strategy on Hydrogen | Publication | Government.nl

renewable energy resources in the world. Due to our location in the Atlantic, Ireland's coast is one of the most energy productive in Europe. One of the main challenges to the supply of renewable hydrogen is the availability of renewable energy to produce it. Our considerable offshore wind resource means that Ireland has the potential to produce significantly more renewable hydrogen than we will need to meet our own indigenous needs. This opens the opportunity for Ireland to become a net exporter of renewable hydrogen in the long-term where other European countries are actively looking to source new supply routes to import renewable hydrogen. With our location in Europe, coupled with existing coherency on energy policy and infrastructure links, Ireland is particularly well placed to potentially be a supplier of renewable hydrogen to the European market.

It is also important to note that the starting point for hydrogen in Ireland is different from many other countries in Europe that already produce and consume large quantities of fossil fuel derived "grey hydrogen". With little to no existing hydrogen production or end-uses on the island today, the challenge in the Irish context will be to develop and scale up a hydrogen sector which currently does not exist. However, this means that Ireland does not have the same need to decarbonise to existing hydrogen supply in the short term through technologies like carbon capture and storage. Ireland can instead develop a new indigenous hydrogen sector which maximises the opportunities presented by the production and use of renewable hydrogen.

Ireland imported 77% of its energy supply in 2021, up from 72% in 2020[10]. Developing an indigenous renewable hydrogen industry in Ireland offers a pathway to reducing this reliance and could ultimately lead to energy independence in the long-term. The value of this has been demonstrated clearly in recent times with the ongoing energy crisis in Europe.

Delivering competitively priced, secure, and clean renewable energy will be an essential building block to decarbonising our economy. Decarbonised gases such as renewable hydrogen should become a critical component of Ireland's energy ecosystem in the longer term and can play a significant role in enhancing sector coupling between the energy carriers, delivering a more integrated energy system for Ireland, with the overall aim of minimising the overall cost of decarbonisation to consumers across all sectors. Whilst the targets and momentum behind the development of hydrogen globally are significant, renewable hydrogen is still very much a nascent technology with great uncertainty still. Significant developments are needed across the entire value chain including cost reductions, supply chains, transportation, and storage to deliver on these ambitions. A National Hydrogen Strategy is therefore a key enabling building block to ensure that we have the knowledge, the correct policy supports and resources in place to enable the scale up and roll out of a renewable hydrogen industry in Ireland. The development of this strategy is just the first step required to make this proposition a reality. Continued work to deliver the associated actions and next steps outlined throughout will also be required to achieve our goals. The government is committed to the continued support for the establishment of a sustainable renewable hydrogen industry in Ireland, which is closely integrated with our overarching energy, economic and climate goals.

[10] https://www.seai.ie/data-and-insights/seai-statistics/key-publications/national-energy-balance/#comp00006023933e000000bbbe3751

1.1 Policy Context

The development of a hydrogen strategy has interlinkages with several other government policy papers that are already published or in development. These set clear parameters under which the National Hydrogen Strategy must ensure coherence. A summary of some of these key policy statements are listed below.

Table 3: Summary of Major Policy Statements relevant to the National Hydrogen Strategy

Major Policy Statements 2020-2023	
Climate Action and Low Carbon Development (Amendment) Act 2021	• The Act commits Ireland to a legally-binding target of a climate neutral economy no later than 2050, and to a reduction in emissions of 51% by 2030. • The Act provides the framework for Ireland to meet these targets, including the preparation of Sectoral Emissions Ceilings and the setting of Carbon Budgets. • The 2022 Sectoral Emissions Ceilings included the delivery of an additional 2GW of offshore wind, earmarked for the production of renewable hydrogen, to be in development by 2030.
Climate Action Plan 2023	• The Climate Action Plan 2023 is the second annual update to the Climate Action Plan 2019 and sets out how Ireland can accelerate the actions that are required to respond to the climate crisis, putting climate solutions at the centre of our social and economic development. • The Plan sets out that decarbonised gases such as renewable hydrogen will be a critical component for Ireland's energy ecosystem and in the longer term can play a significant role in sector coupling (the increased integration of energy supply and end-use sectors), and in minimising the overall cost of decarbonisation across all sectors. • The Plan's KPIs include renewable hydrogen in production from surplus renewable electricity by 2030, zero emission gas fired generation commencing by 2030, and renewable hydrogen production via 2 GW of offshore wind under the 2031-2035 measures.
Long-term Strategy on Greenhouse Gas Emissions Reductions	• This Strategy builds upon the decarbonisation pathways set by the carbon budgets, sectoral emissions ceilings and Climate Action Plan 2023, to ensure coherent and effective climate policy. • It sets out indicative pathways, beyond 2030, towards achieving carbon neutrality for Ireland by 2050 • It is underpinned by analysis of transition options across each key sector of the economy and provides a crucial link between Ireland's 2030 climate targets and the long-term goal set by Ireland's National Climate Objective and the European Climate Law.
National Energy Security Framework	• This Framework provided a response to Ireland's energy security needs in the context of the war in Ukraine. • It focused on how to support households and businesses, in particular those most at risk of fuel poverty, and how to accelerate the country's shift to increased energy efficiency and indigenous renewable energy systems. • The Framework also prioritised the development of a hydrogen strategy for Ireland.

continued

Major Policy Statements 2020-2023 *(continued)*	
Government Statement on the Role of Data Centre in Ireland's Enterprise Strategy	• This Statement seeks to enable the 'twin transitions' of digitalisation and decarbonisation of our economy and society. These transitions can – and must be – complementary. For this to happen, digital and climate change policies need to move in tandem and this Statement sets out how this will be achieved in respect of data centres. • The Statement highlights the CRU Decision (CRU/21/124) that new data centre connections are required to have on-site generation (and/or battery storage) that is sufficient to meet their own demand and, to assist in full decarbonisation of the power system, this generation should also be capable of running on renewably sourced fuels (such as renewable gas or hydrogen) when supplies become more readily available.
Policy Statement on Petroleum Exploration and Production in Ireland	• This Statement confirmed that whilst no new authorisations for new exploration will be granted, existing authorisations are not affected by this change. • Holders of existing authorisations can continue to apply to progress through the standard licensing lifecycle stages towards a natural conclusion, which may include expiry, relinquishment, or production. • Any applications for follow-on authorisations or applications to undertake offshore activities under an authorisation are subject to Ministerial consent and must continue to meet environmental, technical, and financial criteria as appropriate.
Ireland's Road Haulage Strategy 2022-2031	• This Strategy focuses on generating efficiencies, improving standards, securing jobs and helping the road freight sector move to a low-carbon future. • It sets out the measures and supporting policies needed to deliver on these objectives, in particular for decarbonisation. • Under Action 14 of the Strategy, the role that hydrogen can play in the decarbonisation of heavy goods road freight is to be part of the development of the National Hydrogen Strategy.
Shared Island Initiative	• Both Ireland and Northern Ireland now have common carbon emission reduction goals and statutory requirements. The cross-border connections in energy and transport, and in broader economic terms, provide important opportunities for strategic cooperation on green energy transition on a shared island basis. The revised National Development Plan (2021-2030) includes a priority on exploring potential cross-border and all-island approaches on renewable energy, including on the potential of hydrogen power. • Already, as part of the Shared Island initiative, both Administrations on the island are supporting a feasibility study to assess the potential to establish hydrogen refuelling stations along the main road network between Dublin and Belfast, which is the most intensively used transport route by heavy duty vehicles on the island.

In addition to the above, there are several future actions being progressed under Climate Action Plan 2023 which will have relevance to the development of future hydrogen policy in Ireland as listed below:

Table 4: List of relevant Climate Action Plan 2023 actions

#	Action	Owner	Stakeholders	Due Date
EL/23/15	Publish public consultation on private wires with published policy to follow and, if necessary, Government enact facilitating legislation	DECC	DETE	Q4 2023
EL/23/28(TF)	Develop Strategy for OWE enterprise development based on Enterprise White Paper	DETE	EI, DECC	Q1 2024
EL/23/30(TF)	Carry out ORE/maritime/planning skills assessment report	DFHERIS	DECC	Q2 2023
EN/23/3(TF)	Prepare a decarbonisation roadmap for industrial heat based on the recommendations of the SEAI National Heat Study		DETE	Q4 2023
EL/23/22	Publish a policy framework for electricity storage based on electricity system needs	DECC		Q3 2023
BE/23/26(TF)	Publish a National Heat Policy Statement	DECC	SEAI, DETE, DHLG, DAFM, DPER, DTAGSM, DHFERIS	Q3 2023
TR/23/45*(TF)	Identify pathway to appropriate decarbonisation of interurban rail services, informed by Strategic Rail Review	NTA, Iarnród Éireann	D/Transport	Q4 2023
TR/23/61	Publish draft National Policy Framework on Alternative Fuels	D/Transport	Transport Operators, Ports, Airports	Q4 2023*
TR/23/63	Publish updated RTF Policy Statement for 2023-2025 period	D/Transport	DECC	Q3 2023
TR/23/64*	Promotion of Renewable Fuel Use in Maritime Transport – examination and planning for shore-side electricity in ports under AFIR and Fuel EU Maritime regulations	D/Transport	Maritime Ports, IMDO	Q4 2023
AG/23/13	Deliver a National Biomethane Strategy	DAFM	DETE, D/Transport, D/Finance, DPER, D/Housing, EPA DECC, LAs, ISIF, Teagasc	Q3 2023

*Publication deadline amended to Q4 2024, in light of pending policy at EU level"

1.2 EU Policy Context

Several EU policy developments and initiatives are also highly relevant to Ireland's National Hydrogen Strategy. These set clear ambitions and principles for Member States to consider in the development of national policy and measures to enable cooperation and cross border activities in this area. A summary of some of these key policy statements are listed below.

Table 5: Summary of Major EU Policy Statements relevant to the National Hydrogen Strategy

European Major Policy Statements 2020-2023	
EU Hydrogen Strategy	• Sets out a vision of how the EU can turn clean hydrogen into a viable decarbonisation solution • An investment agenda for the EU • Boosting demand for and scaling up production • Designing a framework for hydrogen infrastructure and market rules • Promoting research and innovation in hydrogen technologies
EU Energy System Integration Strategy	• Sets out the need to develop a more integrated energy system and optimise the use of existing assets to deliver the energy transition at least cost • The strategy calls for application of the "energy efficiency first" principle, an acceleration of the electrification of energy demand and the promotion of renewable and low carbon fuels for sectors where electrification will not be feasible, or cost effective.
EU Hydrogen and Gas Market Decarbonisation Package	• Sets out proposed changes to the 2009 package, which set the market rules under which natural gas undertakings can operate • The revised packaged has five core objectives: 1. To create a legislative framework for establishing an EU hydrogen market 2. To facilitate the integration of Renewable and Low Carbon gases onto the network 3. To protect and encourage more active consumer participation in the market 4. To foster more integrated network planning 5. To enhance resilience and security of supply
RePowerEU	• The European Commission's plan to reduce the European Union's dependence on Russian fossil fuels by diversifying gas supplies and speeding up the roll-out of renewable gases • Sets an EU target of 10 million tonnes of domestic renewable hydrogen production and 10 million tonnes of imports by 2030
Fit for 55	• Fit for 55" contains a host of legislative packages including the recast Renewable Energy Directive, the Alternative Fuels Infrastructure Directive, ReFuelEU Aviation and FuelEU Maritime, amongst others • These legislative proposals set out the requisite actions to deliver a 55% reduction in greenhouse gas emissions by 2030 across the EU • They include specific targets for renewable hydrogen in end use sectors such as transport, industry, Aviation and Shipping

2 Hydrogen Production

Key Messages

- Ireland will prioritise the scale up and production of renewable hydrogen.
- Prior to 2030, hydrogen will be produced from grid connected electrolysis from surplus renewables. This will initially be needed to meet EU targets in specific end-use sectors such as transport and will likely be used in the power system. The operating models for these should be beneficial to the electricity system and sufficient grid infrastructure is needed to facilitate this.
- A 2 GW target of offshore wind, for the production of renewable hydrogen, to be in development by 2030, will help to provide greater certainty for investors and create the volumes needed to scale up the sector.
- Ireland has one of the best offshore wind resources globally and has the potential to develop a decarbonised industrial opportunity in proximity to this resource, and to become a net exporter of renewable hydrogen in the longer term.

2.1 Hydrogen Production Pathways

Hydrogen is the most abundant element in the universe. Given its small molecular size it is normally found chemically bonded to other elements, primarily water (H_2O) and hydrocarbons (CxHx). Producing hydrogen requires these chemical bonds to be broken down and the hydrogen to be separated and stored. Doing so requires an energy input, typically in the form of electricity or heat. The source behind this energy input, and the resulting by-products from the process influence how carbon intensive the hydrogen production process is. Figure 1 taken from recent analysis from the IEA outlines the emissions intensities of different production pathways.

Most hydrogen produced globally today is fossil fuel based "grey" hydrogen, meaning it has been produced from hydrocarbons without any emissions abatement of the carbon by-product. This is a carbon intensive and non-sustainable form of production. Given the strategic role envisioned for hydrogen in Ireland is primarily to support the delivery of an integrated net zero energy system, it is essential that hydrogen production supports this long-term goal. The relevant sustainable production pathways for Ireland are discussed in more detail in this Section.

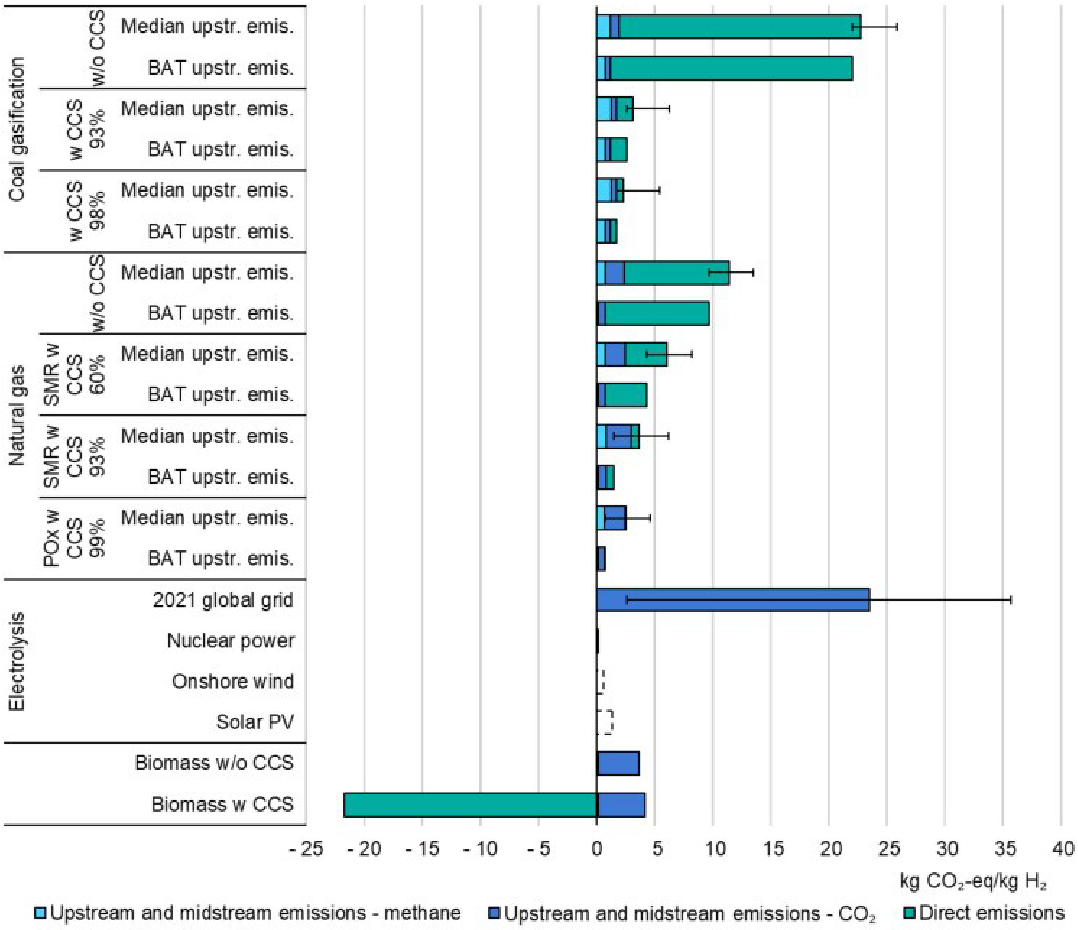


Figure 2: Comparison of the emissions intensity of different hydrogen production (Source: IEA[11])

2.1.1 Electrolysis of Water

Overview

Hydrogen can be produced from electrolysis of water, using electrical energy to split the water molecule into hydrogen and oxygen as a by-product. If this electrical energy comes from a renewable source, such as wind or solar, it can deliver a high purity hydrogen with no associated emissions and is a renewable form of hydrogen (often referred to as "green hydrogen").

Availability of Renewables

Renewable hydrogen from electrolysis requires significant volumes of renewable electricity to produce it. Energy losses during the conversion process mean that the hydrogen produced contains only around 60-70% of energy content of the original renewable electricity supplied (although new technologies under development have reported test efficiencies of 80%-84%[12]). While Ireland has the resource potential to produce significant volumes of renewable hydrogen, it will take time to deploy the required onshore and offshore renewables at the sufficient scale.

11 Towards hydrogen definitions based on their emissions intensity – Analysis – IEA

12 Electrolysers – Analysis – IEA

Our target of 80% renewable electricity by 2030 will mostly be dedicated to decarbonising power generation and supporting the expanding electrification of the heat and transport sectors. However, analysis undertaken as part of the Climate Action Plan 2023 estimates that our 80% target could also support as much as 2-4 TWh of renewable hydrogen production by 2030[13]. This may increase substantially with the detailed design of the electricity network in the second version of shaping our electricity future to be published this year. A portion of this potential would be directly attributed to the potential role hydrogen could play in reducing system curtailment, also estimated to be c. 16% by 2030 (or 9.7 TWh)[14]. EirGrid are currently finalising their work on Shaping Our Electricity Future[15] and will provide updated figures on this as part of this work.

Beyond this, greater use of Ireland's offshore renewable energy resources will be required. In March 2023, the Department launched the Policy Statement on the Framework for Phase Two Offshore Wind[16]. The Framework sets out Ireland's longer-term vision for offshore wind energy, targeting 20 GW of offshore production by 2040 and at least 37 GW by 2050, opening the opportunity to significantly ramp up renewable hydrogen production post 2030.

Costs

The costs of renewable hydrogen production are primarily driven by two key factors, the cost of renewable electricity and the capital costs of electrolysers. Electrolyser capital costs have dropped significantly in recent years and are projected to continue to do so. Utility scale solutions are now becoming available and supply chains are ramping up with many equipment providers beginning to offer products in the 100 mega-watt scale and moving towards giga-watt scale. These technological developments are putting a significant downward pressure on the production costs of renewable hydrogen with electrolyser costs predicting to roughly halve by 2030 and drop to one third by 2050[17].

With renewables costs also continuing to fall, renewable hydrogen costs are expected to fall dramatically over the coming decades, with some predicting it may become the cheapest form of low carbon hydrogen production by as early as 2030[18], when predicted increases in carbon prices are accounted for. Ireland's renewable energy resources are some of the most energy productive in the world, and these falling costs will greatly improve the competitiveness of Irish produced renewable hydrogen.

The Hydrogen Council, an initiative that includes 150 multinational companies representing the entire hydrogen value chain, predicts the costs of renewable hydrogen could fall to as low as low as 0.9-1.6 $/kg by 2050, which equates to roughly €2.5-4.5 c/kWh by 2050. These costs would be comparable to the typical market prices seen for fossil fuels such as natural gas over the past decade, showcasing the potential opportunity that renewable hydrogen could offer in a future net zero energy system.

13 39588f58-81ed-4631-82fc-11d6d6d55dea.pdf (www.gov.ie)
14 3ddf7b83-8ee8-4d62-b35e-d3dea38fa433.pdf (www.gov.ie)
15 Shaping our Electricity Future (eirgridgroup.com)
16 draft_Phase Two Consultation Paper_branded – bbd8b13c-73cd-46d4-9902-533fbf03d7fe.pdf (www.gov.ie)
17 The Future of Hydrogen – Analysis – IEA
18 'Green' Hydrogen to Outcompete 'Blue' Everywhere by 2030 | BloombergNEF (bnef.com)

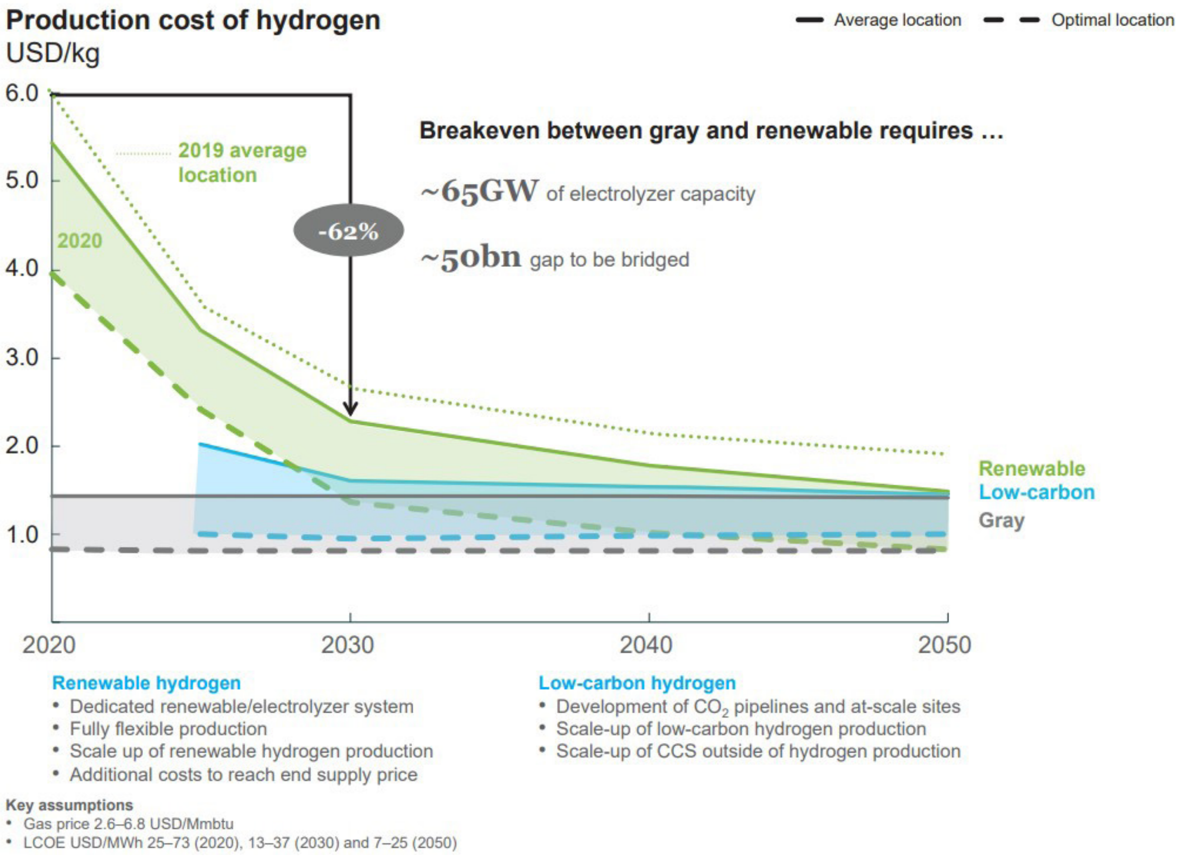


Figure 3: Estimated future production costs of hydrogen by production pathway (Source: The Hydrogen Council[19])

Water Needs

As well as electricity, electrolysis also requires large quantities of water as an input. Ireland is not expected to have significant issues supplying the quantities of water required to produce renewable hydrogen. For example, supplying 2 GW is estimated to require less than 1% of Ireland's current water supply including leakages. In addition, water can also be sourced from local sources, such as rainwater, aquifers/streams, as well as through desalination of sea water, which is particularly relevant in the case of hydrogen production from offshore renewable sources. Post treatment wastewater from water treatment plants may also offer a solution.

Individual electrolysis projects will be required to comply with the Water Framework Directive, and this can be assessed through their consenting process to ensure no adverse effects to the environment occur as a result. However, it will be important to engage with Uisce Éireann as the sector develops to ensure any potential future water needs for the hydrogen sector are understood and that sufficient infrastructure investment in the water network can be made in advance so that no localised supply issues emerge.

[19] Hydrogen-Insights-2021.pdf (hydrogencouncil.com)

Grid Connected Electrolysis

Hydrogen can be produced from electrolysis by either directly connecting to a renewable electricity source, or alternatively by using power from the national electricity grid. When using the latter, the emissions intensity of the hydrogen is determined by the sources of electricity feeding the national grid. In 2021, 23.9% of Ireland's primary energy inputs to electricity came from renewables[20]. However, with our target of 80% renewable electricity by 2030 and long-term ambitions to achieve a near net zero power system by 2035, grid electricity ultimately has a pathway to becoming a zero-carbon source of electricity. In the interim period, clear rules are needed to determine if and when electrolysis connected to the electricity grid can be deemed renewable or not, as discussed in more detail below.

Grid connected electrolysis also opens possibilities in terms of sector coupling with the ability to provide grid flexibility services and reduce curtailment by running electrolysers during periods of high wind/low demand. This also correlates well with times where the electricity market prices and the emission intensity of the grid are lowest, potentially offering opportunities for hours of low-cost sustainable hydrogen production. Analysis produced for the Climate Action Plan estimated system curtailment by 2030 to be in the region of 16% by 2030 (or 9.7 TWh), in the absence of additional measures to reduce it[21]. EirGrid are currently finalising their work on Shaping Our Electricity Future[22] and will provide updated figures on this as part of this work. Further analysis should also be undertaken to determine more granularly the quantities of curtailment expected out to 2030 and publish regional load duration curves with this information.

Rules for Determining if Grid Electrolysis is Renewable

The flexibility of operation that grid electrolysis provides also means it is possible to operate them in a manner which is less beneficial to the grid and produces less sustainable hydrogen. To reduce this risk, the European Commission has developed their draft delegated act on additionality[23]. This sets out the criteria under which grid electrolysis can be deemed to be renewable, as summarised below:

- A power purchase agreement must be in place with a renewable electricity source, constructed within a 36-month period of the electrolyser, and which has not received operating aid.
- The electrolyser must be located within the same bidding zone as the renewable source.
- The time difference between the renewable electricity and the hydrogen being produced cannot exceed one month initially, reduced to hourly from 2030.

Hydrogen produced from grid electrolysis can also be considered as renewable if produced in an electricity system with greater than 90% renewables over a calendar year or if produced during periods of curtailment or dispatch down.

The delegated act does not preclude hydrogen being produced from electrolysis under other conditions, however it means that hydrogen will not be accredited as renewable. This will impact the market value of the product and should disincentivise these production practices. Ensuring alignment with these rules will be a minimum requirement for any hydrogen production that is to be supported by the government.

[20] Energy In Ireland | Key Publications | SEAI
[21] 3ddf7b83-8ee8-4d62-b35e-d3dea38fa433.pdf (www.gov.ie)
[22] Shaping our Electricity Future (eirgridgroup.com)
[23] Production of renewable transport fuels – share of renewable electricity (requirements) (europa.eu)

Grid Connections and Reinforcements

A secure and reliable grid connection is also essential for grid electrolysis. Ireland's electricity system demand is forecast for grow by 41% over the next 10 years[24], which will already place significant pressure on reinforcing the network. As grid electrolysis could further exacerbate this, an appropriate grid connection policy is needed to ensure the prioritisation of electrolysis connected that operates primarily during periods of high wind and curtailment, rather than resulting in additional constraint to the system.

Operating Models for Grid Electrolysis

Several potential operating models for grid electrolysis have been proposed, varying from low run hours during periods of high renewables, to "always on" trying to maximise utilisation of the capital investment in the electrolyser. Some of these will deliver significant system benefits whilst others will not. It will be important to consider how priority of connection capacity can be allocated to those projects who are expected to deliver the most system benefits. The below summarises several potential operating models.

Table 6: Grid electrolysis operating models

#	Operating Model	Description	System Benefits	Pros and Cons
1	**Curtailment model**	Electrolysers run during times of high wind to reduce curtailment/ dispatch down on the system		• Can deliver some reduction of curtailment, subject to sufficient grid capacity. • Low run hours associated meaning the high capex cost of electrolyser may result in a high levelised cost of hydrogen (LCOH) production.
2	**Electricity Marginal Pricing Model**	Electrolysers run during lowest market price periods, which typically correlates with high renewables or low demand		• Can deliver reduction of curtailment. • Strong correlation between high penetration of renewables/low system demand and low market price. • Additional run hours may result in a lower overall LCOH than the curtailment only model.
3	**System services model**	Electrolysers operate at c.50% full load, providing the ability to ramp up or down, delivering balancing and operating reserve system services		• Delivers system services benefits for the system. • High efficiency losses compared to alternative technologies such as batteries. • Electrolyser typically only operates at c. 50% load factor.

continued

[24] EirGrid_SONI_Ireland_Capacity_Outlook_2022-2031.pdf (eirgridgroup.com)

#	Operating Model	Description	System Benefits	Pros and Cons
4	**Always run model/ hydrogen demand following**	Electrolysers run as close to full load as possible to maximise the volume of hydrogen produced	Low System Benefits	• Can result in additional load during periods of low renewables or high demand. • High utilisation rate of electrolysers • Enables the producer to amend their production pattern to meet the consumption needs of an end user, potentially reducing costs associated with transportation and storage.
5	**Grid back-up model**	The electrolyser runs off grid electricity when non grid connected renewables are not available.	Low System Benefits	• Results in additional load on the system only during periods of low renewables or high demand. • This enables producers using directly connected renewables to have a high utilisation rate of their electrolyser, which could result in a lower LCOH to them. • Demand grid charges are predominantly driven by consumption, rather than capacity. This model would result in the producer delivering the least system benefits and providing a lower financial contribution to grid charges.

Low System Benefits | Some System Benefits | High System Benefits

2.1.2 Low Carbon Hydrogen

Hydrogen produced from fossil fuels can reduce the emissions from the production process via carbon capture and storage (often referred to as “blue hydrogen”). Though not a renewable gas, it could be a low carbon one, with an emissions intensity roughly 70% lower than that of natural gas for example[25]. Low carbon hydrogen can reduce the emissions of existing fossil fuel derived hydrogen and enable scaling up of supply in the short term, in the absence of sufficient renewables being available to produce renewable hydrogen. However, low carbon hydrogen production would perpetuate Ireland’s dependence on imported fossil fuels and does not deliver any benefits in terms of our energy security needs. As it requires carbon capture and storage facilities/export routes at a scale that do not currently exist in Ireland, low carbon hydrogen production would not necessarily offer a quick scale up of supply. Finally, whilst low carbon hydrogen does offer a reduction in emissions, it is not a zero-emission solution and therefore inconsistent with our long-term national climate goals. On this basis, low carbon hydrogen production is not anticipated to play a significant role in Ireland.

[25] 2020s, central case scenario; for more detail on carbon intensity estimates, see: Department for Business, Energy and Industrial Strategy (2021), ‘Consultation on UK Low Carbon Hydrogen’; E4tech (UK) Ltd and Ludwig-Bölkow-Systemtechnik GmbH (2021), ‘Low Carbon Hydrogen Standard’ (viewed 21 June 2021)

2.1.3 Hydrogen Production Through Bioenergy with Carbon Capture and Storage (BECCS)

Hydrogen can also be produced in a way which can potentially deliver negative emissions, through the replacement of the fossil fuel input with a bioenergy source and utilising the same production technologies as low carbon hydrogen production. The input feedstock for this could be either solid biomass or biomethane. Ireland has a target to deliver 5.7 TWh of biomethane production by 2030. Longer term, bioenergy is estimated to be able to deliver up to 11.6 TWh indigenously, including solid biomass resources[26]. It is envisioned that much of these resources will be used to supply directly sectors such as high temperature heating.

As identified in the Long-term Strategy on Greenhouse Gas Emissions Reductions[27], some emissions will remain in our economy by 2050, requiring sufficient levels of carbon dioxide removals to maintain an annual balance of emissions and removals from 2050 onward. This production pathway could offer a potential mechanism for delivering part of this need in the long-term, subject to the required bioenergy resources being available. However, negative emissions can also be delivered through post combustion capture of bioenergy, or through the likes of Direct Air Capture technologies and so the potential production of hydrogen from BECCS must be considered in this broader context.

One of the recommended actions from the Long-term Strategy on Greenhouse Gas Emissions Reductions is to develop a strategy for negative emissions technologies. The potential production of hydrogen from BECCS should be considered as part of this future work programme.

Case Study

Mount Lucas Green Hydrogen Production Project

Bord na Móna and BOC Gases are jointly developing a 2 MW green hydrogen project at our existing Mount Lucas wind farm in Co. Offaly. Planning consent for this project was granted in May 2023. Once operational, the project will produce approximately 200,000 kg of green hydrogen annually, powered by wind energy, and will be predominantly used to decarbonise the mobility and industrial heating sector and could reduce CO_2 emissions within those sectors by up to 4,000,000 kg every year. Target delivery of the operational project is 2025. The project will not only prove production, handling, and distribution of Green Hydrogen in Ireland, but also key health and safety compliance standards to be further developed for the hydrogen industry.

26 Sustainable-Bioenergy-for-Heat.pdf (seai.ie)
27 gov.ie – Long-term Strategy on Greenhouse Gas Emissions Reductions (www.gov.ie)

Figure 4: Graphic representation of Mount Lucas Green Hydrogen Production Project

2.2 Scaling Up Renewable Hydrogen Production

In the long-term, it is envisioned that there will be a liquid and mature market for hydrogen with the same level of cost-competitiveness, investor certainty, transport infrastructure and supply routes that exist for the mainstream energy carriers today. However, renewable hydrogen production is a nascent technology and in the early years policy signals and supports will be needed to reduce the price differential between renewable hydrogen and fossil fuels, create greater investor certainty and ultimately drive private investment. To achieve this, we will deliver on the following:

Develop a National Certification Scheme for Hydrogen Production Methods

The EU delegated act on additionality sets out the rules by which hydrogen produced directly from renewables or grid electricity can be considered as renewable. This is currently pending approval within the EU institutions and is anticipated to be finalised around June 2023. A separate delegated act for low carbon hydrogen is proposed as part of the EU Hydrogen and Decarbonised gases market package and is at an earlier stage of the development process. Once implemented, a national certification scheme will be required to certify the sustainability of hydrogen produced nationally to provide certainty to end users as to the origin and sustainability of the hydrogen they are producing. This certification system must be integrated closely with the current Guarantee of Origin schemes for renewable electricity and renewable gases in place in Ireland today to ensure that double counting of credits for both renewable electricity and renewable hydrogen do not occur.

Establish a Hydrogen Demonstration Fund to enable Early Innovations across the Value Chain

Demonstrator projects can help to create more transparency and a better understanding of the technology, the commercial business models and help to identifying and alleviate potential barriers that may exist for future projects. They also offer a chance for end-users and the public to physically see and experience the hydrogen technology. This experience is key to public buy in and providing the necessary reassurances to prospective end-users.

On this basis, Government commits to supporting pilot projects that can demonstrate renewable hydrogen technology in an Irish context across the value chain, that demonstrate and develop our regulatory regime and can provide early evidence of the market opportunity for renewable hydrogen. It is expected that collaborative pilots will deliver the most learning. An initial investment fund will be made available to support these pilot projects. Further Government support may be required to build commercial routes to market for larger projects towards the end of the decade. Further details on this fund will be communicated shortly after the publication of this strategy.

Deliver on Our 2030 EU Requirements in the Transport Sector

Certain end use sectors such as transport, with the recast of the Renewable Energy Directive[28] which is being finalised in the European institutions currently, will have specific sub targets for renewable fuels of non-biological origin (RFNBOs) to be delivered by 2030. These targets are expected to require a minimum of 1% of transport demand to be supplied with RFNBOs per Member State, with an additional 5.5% target to be split between RFNBOs and advanced biofuels. To meet this minimum obligation will require around 0.5 TWh of hydrogen to be produced and targeted to transport end uses by 2030, and this could rise to around 2.5 TWh if the higher 5.5% target was to be fully supplied by RFNBOs.

It is envisioned that much of this early hydrogen production will be from grid connected electrolysis, with the potential for reduction of overall curtailment volumes through operating electrolysers predominantly during periods of high renewables on the system, coupled with some other renewable energy sources.

The Department of Transport's current Renewable Transport Fuel Obligation Regulations on additional certs for certain renewable fuels in 2023 already allows for suppliers to be awarded a x4 credit if they meet their obligation using RFNBOs. This policy will be kept under review in light of these new EU requirements. The Department of Transport will soon be publishing the Renewable Transport Fuel Policy 2023-2025[29] following a consultation which considered these aspects further.

Deliver 2 GW of Offshore Wind for the Production of Renewable Hydrogen

With a sea area approximately seven times the size of its landmass, Ireland has one of the best offshore renewable energy resources in the world. Due to our location in the Atlantic, Ireland's coast is one of the most energy productive in Europe with significant potential for offshore wind production. With this in mind, an initial target of 2 GW of offshore wind, dedicated to the production of renewable hydrogen, was agreed under the Sectoral Emissions Ceilings. This is targeted to be in development from 2030 and deliver emissions savings to Ireland's sectoral emissions targets between 2031-35. Given the typically large sizing of offshore wind farms, this will ensure renewable hydrogen is produced in a way which ensures the necessary economies of scale to be competitive whilst also creating strategic centralised supply routes through which

[28] Renewable energy directive (europa.eu)
[29] gov.ie – Consultation on the Draft Renewable Transport Fuel Policy Statement 2023-2025 (www.gov.ie)

geographic high priority demand clusters will begin to develop. Further details on this production target will be provided in the upcoming Phase Three and Offshore Wind Future Framework policies, alongside a National Industrial Strategy for Offshore Wind.

A Willingness to Explore Further Opportunities as they emerge

There are significant opportunities to engage within the EU in knowledge sharing, co-investment, and collaboration. This Strategy commits Ireland to further explore opportunities created at EU level to support innovative projects along the hydrogen value chain, for example through any future 'Important Projects of Common European Interest' (IPCEIs), the European Clean Hydrogen Alliance or proposals such as the Net Zero Industry Act.

2.3 Our Long-Term Vision

Hydrogen production is envisioned to expand to meet increasing indigenous demand as end-use sectors transition to renewable hydrogen, synthetic fuels are produced using renewable hydrogen and to support potential future export market opportunities that may emerge. Exact quantities will be dependent on several factors including global competitiveness, technological advancements, and end-user demand. The long-term ambition of the government is to develop 20 GW of offshore renewable energy production by 2040 and at least 37 GW by 2050. This equates to roughly 150 TWh per annum and coupled with onshore renewables, will be in excess of our indigenous needs. If it would be possible to realise Ireland's entire theoretical offshore resource potential, it is estimated at 2,852 TWh[30]. While it may not be feasible to achieve all of this, it shows the scale of the export opportunity that may exist in the long-term.

Onshore renewables will also contribute to the production of renewable hydrogen. Once hydrogen transportation and storage become more accessible nationwide, this opens greater opportunities for inland production in terms of enabling infrastructures. The precise split of onshore/offshore renewables to the production of renewable hydrogen will eventually be determined by the market. However, the availability of sufficient renewables to meet both our indigenous needs and future export opportunities is reliant on achieving our potential in the offshore renewables space.

Aligned with this ambition, and wider industrial development opportunities, the Department of Enterprise, Trade and Employment (DETE) will publish a National Industrial Strategy for Offshore Wind in 2024 setting out how Ireland can maximise the economic opportunity arising from the production of Offshore Wind Energy. This Strategy is expected to include measures to develop both indigenous and export demand for energy derived from Offshore Wind which may include the large-scale production of hydrogen and its derivatives. The Industrial Strategy will be developed in close consultation with the Department of Environment, Climate, and Communications, the Offshore Wind Delivery Taskforce, as well as other key Departments, Agencies, and industry.

[30] 7338cf63-e174-4932-8c61-6b840e447f3d.pdf (www.gov.ie)

Actions

1. Develop and publish data sets showing the likely locations, volumes, and load profile of surplus renewables on our electricity grid out to 2030
2. Establish an early hydrogen innovation fund to provide co-funding supports for demonstration projects across the hydrogen value chain
3. Adopt EU standards for renewable and low carbon hydrogen and develop a national certification scheme to provide clarity to end users as to the origin and sustainability of their hydrogen
4. Develop the commercial business models to support the scale up and development of renewable hydrogen, targeting surplus renewable grid electricity pre-2030 and an initial 2 GW of offshore wind from 2030

3 End-Uses of Renewable Hydrogen

Key Messages

- The deployment of renewable hydrogen in Ireland will focus on hard-to-decarbonise sectors where energy efficiency and direct electrification are not feasible or cost-effective solutions.
- Heavy duty transport applications where there are binding EU targets for 2030 are anticipated to be the first end use sectors to develop, followed closely by industry and flexible power generation.
- Aviation and maritime are expected to be large high priority end-users but these sectors will take longer to develop.
- Indicative projections estimate that Ireland's domestic hydrogen energy demand needs could equate to between 4.6 and 39 TWh by 2050. When including non-domestic energy needs such as International Aviation and Shipping, these values could rise to between 19.8 to 74.6 TWh. This wide range demonstrates the significant uncertainties which exist due to the nascent nature of the market.
- Future work is needed to better understand the needs of potential end-use sectors, the volumes of renewable hydrogen required within these sectors and the role that renewable hydrogen can play in an integrated net zero energy system.

3.1 Renewable Hydrogen in Ireland's Integrated Net Zero Energy System

Renewable hydrogen is a versatile energy carrier which offers a renewable and net zero alternative to fossil fuels in many areas of our energy system. For many sectors and end-uses, energy efficiency and direct electrification will offer a cheaper and more energy efficient solution to decarbonisation. However, there will be some sectors where these will not be feasible or cost-effective solutions. For these hard to-abate sectors, decarbonised gases like renewable hydrogen will be critical for reducing emissions and transitioning to a net zero economy. Therefore, Ireland's strategic approach to decarbonisation is to concentrate first on energy efficiency, direct electrification, and finally targeting renewable and low carbon fuels, such as hydrogen, for sectors that are hard to decarbonise.

Ireland's starting point in terms of hydrogen demand is different to many other countries. At present, Ireland has relatively little hydrogen end-use compared to many other countries in Europe who already consume significant quantities of high emissions intensity fossil fuel derived hydrogen. Whereas others are looking to decarbonise their existing hydrogen demand in the short term through technologies like carbon capture and storage, Ireland will need to create and scale up new hydrogen demand uses which currently do not exist at a significant level. This gives flexibility to ensure that the deployment of renewable hydrogen in our energy system is focussed on difficult to decarbonise sectors. In Ireland specifically, hydrogen is envisioned to play an important role in in the coming years in decarbonising industrial processes, as a long duration energy store, a zero-emission source of dispatchable flexible electricity and as a transport fuel in sectors such as heavy goods transport, maritime and aviation. Priority will be given to developing pure hydrogen applications in these difficult to decarbonise sectors, where the use of renewable hydrogen will maximise emissions' abatement, over sectors where energy efficiency, direct electrification or other solutions have been shown to be the most efficient path to reducing emissions. Lower priority end-uses of hydrogen could also play a minor role in the future as the technology develops and prices reduce; however, policy supports and resources will not be targeting sectors where there are more viable and efficient decarbonisation options. In line with this strategic principle, this Section sets out where in the Irish energy system hydrogen end-uses are anticipated to play a role and the key sectors which will be targeted for the deployment of renewable hydrogen.

3.2 Hydrogen End-Use Priorities

Flexible Power Generation and Long Duration Energy Storage

Renewable hydrogen will have an important role in the electricity sector, both in decarbonising the conventional generation required at times when variable renewable electricity is less plentiful, enhancing energy security by diversifying supply, and as a method of storing electricity from variable renewable generation to address the challenges associated with system stability, seasonal wind variability and curtailment. Ireland has a target of 80% of electricity to come from variable renewable sources by 2030 (which will be increased even further beyond 2030). It is likely that some of this will be required to be renewable dispatchable generation to maintain system reliability and efficient operations. For example, a recent report from the IEA estimates that approximately 5-15% of electricity needs will come from zero carbon dispatchable generation in a net zero power system[31]. Renewable hydrogen used in gas turbines or fuel cells is well placed to meet this requirement.

Most existing gas turbine designs today can already handle hydrogen shares of 3–5% and some can handle shares of 30% or higher. Depending on the turbine design some are also capable of operating under varying hydrogen blends. Significant research is already underway by equipment manufacturers in respect to developing 100% pure hydrogen power turbines. EU Turbines, the association of European gas and steam turbine manufacturers, hold the position that the industry is confident that it will be able to provide standard turbines that are able to run entirely on hydrogen by 2030, with many manufacturers such as Mitsubishi targeting to have these turbines to market as early as 2025[32]. Ireland must build 2 GW of new gas fired generation capacity by 2030, to ensure security of electricity supply[33]. An important consideration when developing this capacity will be how it can transition to zero carbon generation in the future. Ireland's Long-term Strategy on Greenhouse Gas Emissions Reduction states that Ireland will need to achieve near zero emissions from 2035 in the power sector. This will be an important consideration for investors in this new capacity to ensure the long-term viability of their investments. Further work is also needed to better understand the existing capabilities and commercial viability of the existing fleet to run on hydrogen (or blends of hydrogen up to 100%). SEAI are in the process of scoping out a study to determine the future needs of a net zero power system. Further engagement with the power sector to better determine their existing capabilities will be assessed as part of this work.

31 Managing Seasonal and Interannual Variability of Renewables – Analysis – IEA
32 Europe_with_renewable_gas-ready_turbines.pdf (euturbines.eu)
33 gov.ie – Policy Statement on Security of Electricity Supply (www.gov.ie)

In the long-term, renewable hydrogen is expected to have an important role in the long duration storage of electricity as part of decarbonising a net zero emissions power system. Storage technologies like batteries or pumped storage are well suited to shorter term within day flexibility needs, whereas hydrogen's energy density means it can provide a much higher energy density solution, suitable for inter-seasonal storage needs to help manage fluctuations in demand across the seasons and ensure energy security should sustained periods of low wind and solar availability occur. As we connect greater penetrations of variable renewables onto our electricity system, the need for flexible dispatchable zero emission generation becomes more prevalent, particularly as the system approaches and moves beyond the 80% RES target currently proposed. This will result in a need for significant volumes of dispatchable power capacity to be available but run less frequently, with analysis by IEA suggesting future run times of 500-2000 hours per annum compared to 4000 hours typically seen today[34]. Consideration of this fact in respect to the future of the capacity market is also important to ensure sufficient market signals exist in future to support the development of long duration storage and dispatchable zero carbon power generation.

Integrated Energy Parks for Large Energy Users

In recent years, there has been significant interest in locating data centres in Ireland, which now represent 14% of our electricity demand and this is potentially set to expand to 30% by 2030[35]. This speed of growth is unprecedented and comes at a time when the increased electrification of heat and transport, as well as the decarbonisation of our electricity sector, are key strategic priorities for the country out to 2030. In 2022, Ireland published a policy statement in respect to data centres outlining that decisions on future data centre development will be cognisant of several factors, including grid capacity, renewables additionality, co-location with supply and decarbonisation by design[36].

The use of hydrogen as a primary energy source for large electricity users, such as data centres, is considered a low priority end-use, as the direct supply of electricity from renewable sources will be more efficient. However, data centres require a high degree of reliability and typically require on-site backup generation should their electricity supply fail at any point. Given the location specific impacts that large energy users can have on electricity networks, renewable hydrogen in combination with direct renewable sources and co-located with large energy users could be used to fuel on-site back-up generation, alleviating the potential challenges associated with decarbonising these sectors in the short to medium term. In particular, integrated energy parks developments which co-locate large demand users and renewable energy generation alongside energy storage or energy transport infrastructure may offer significant opportunities without placing significant new capacity requirements on our electricity grid.

34 Managing Seasonal and Interannual Variability of Renewables – Analysis – IEA
35 EirGrid_SONI_Ireland_Capacity_Outlook_2022-2031.pdf (eirgridgroup.com)
36 gov.ie – Government Statement on the Role of Data Centres in Ireland's Enterprise Strategy (www.gov.ie)

Case Study

Green Atlantic @ Moneypoint

Green Atlantic @ Moneypoint is an ambitious multi-billion-euro programme of projects that will see ESB transform the coal fired generating station site at Moneypoint on the Shannon Estuary in Co. Clare into a clean energy hub powered by offshore wind from the vast wind resource in the Atlantic Ocean over the coming decade.

The hub will consist of four key projects: a gigawatt scale floating offshore wind farm, a floating wind construction hub, a hydrogen and ammonia production facility and a dispatchable electricity generation facility.

The renewable electricity generated from the floating wind farm will be brought ashore at the Moneypoint site and will be fed directly to the electricity grid or, in times of surplus, can be used to produce renewable hydrogen and zero-carbon ammonia. An ammonia storage facility will be developed onsite and used for clean, dispatchable electricity generation or for other energy uses, such as aviation and shipping.

The development and construction of a new quay facility at the site will facilitate the construction of floating offshore wind platforms. This will provide the necessary infrastructure for the development of the floating wind industry in Irish waters and the achievement of government targets of 37GW of Irish offshore wind by 2050. The quay facility will also enable the export of ammonia, once domestic energy needs are met.

The first phase of the Moneypoint's transformation commenced in 2022, with the deployment of a synchronous compensator. This provides a range of services to the electricity grid which would previously have been supplied by fossil fuelled power generation. Its operation will enable higher volumes of intermittent renewables on the system.

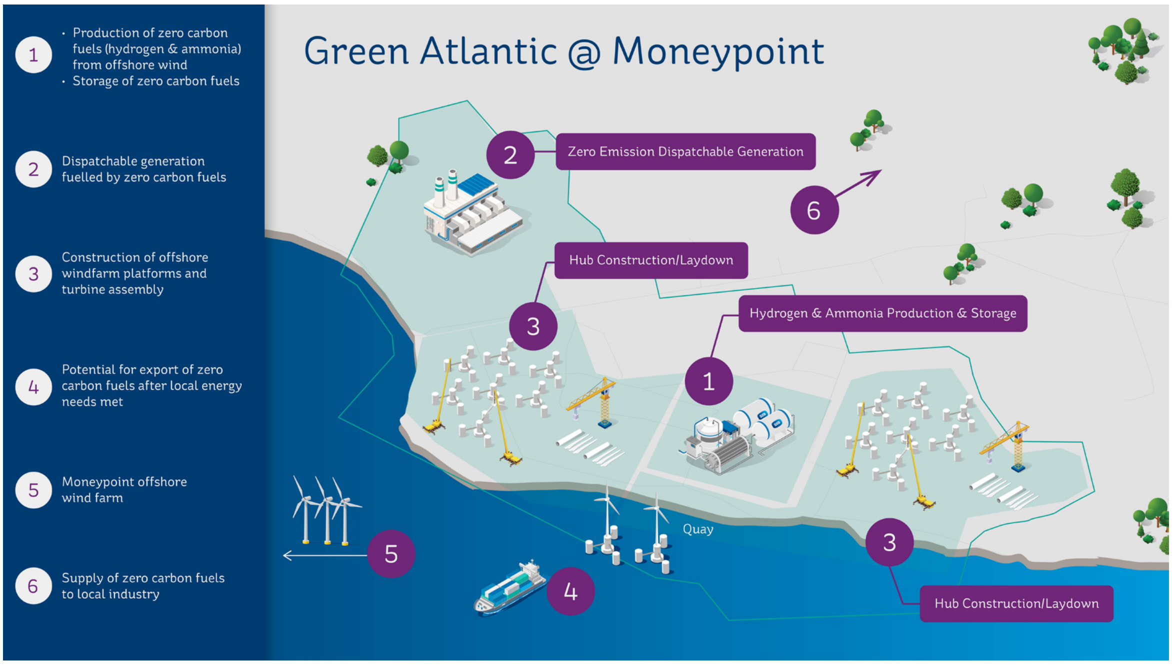


Figure 5: Graphic representation of Green Atlantic @Moneypoint

Industrial Heat and Processing

Industrial applications will be the focus for renewable hydrogen deployment in the heat sector, primarily to produce high grade and medium grade heat in industrial manufacturing processes. Net-zero emission pathways with the lowest cumulative emissions use more electric heating technologies and direct electrification technologies like heat pumps are considered a potentially more efficient and cost-effective solution for decarbonising heating, particular space heating and lower temperature industrial processes (<200 °C). However, higher temperature processes require alternative solutions and, while options such as biomethane are being considered in the short term, hydrogen is one of the few other decarbonised energy carriers that is well-suited for this application, particularly in the longer term. The generation of high-temperature heat for industrial-use accounts for 25% of Ireland's industrial energy demand and represents a significant potential end-use sector for renewable hydrogen[37]. Hydrogen is already used in some industrial processes in Ireland and transitioning that existing demand to renewable hydrogen will be an important early step. Renewable hydrogen can also displace fossil fuels in other large energy use sectors, like the pharmaceutical industry (which accounts for 10% of the overall large energy user demand) and the cement industry (which accounts for 20% of large energy user demand). The Department of Enterprise, Trade and Employment are currently working on the preparation of a decarbonisation roadmap for industrial heat based on the recommendations of the SEAI National Heat Study. The outputs of this work will help to provide further clarity on the future role of renewable hydrogen in the industry and processing sector.

[37] National Heat Study | SEAI

A renewable hydrogen sector of scale, alongside significant renewable electricity availability, can in future provide significant domestic opportunities for net zero manufacturing and services. The White Paper on Enterprise 2022-2030[38] sets out Ireland's objective to align industrial strategy with our decarbonisation objectives and ensure that the opportunities created by renewable energy create real value, employment and prosperity for our enterprise base, economy and society.

Commercial and Residential Heating

Hydrogen is not expected to play a role in commercial and residential space heating. Energy efficiency, direct electrification using heat pumps and the roll out of district heating are expected to be more efficient and cost-effective solutions for this sector. The National Heat Study estimates that heat pumps will be technically feasible in 82% of homes whilst district heating could supply as much as 50% of building heat demand. Hydrogen may play a very minor role for the remainder of the market share, alongside alternative solutions such as district heating, biomethane and biomass boilers. One example of this might be as a back-up fuel source for district heating networks to mitigate any potential risks of the loss of the primary heat source. Overall, there is envisioned to be only a small amount of niche cases where hydrogen may have a role in commercial and residential heating. Energy efficiency will also remain a key consideration for this sector. Even in end-uses where hydrogen heating systems may be installed, they will likely be required to work in parallel with energy efficiency measures such as hybrid heating systems where possible.

Road and Rail Transportation

In the transport sector, where the range and charging patterns of a battery electric vehicle can be accommodated, they generally offer a lower total cost of ownership than fuel cell hydrogen options and are more energy efficient due to the energy conversion losses in producing and using hydrogen in fuel cell electric vehicles (FCEVs). Therefore, hydrogen is not envisaged to have a role in the passenger car fleet as direct electric technologies are already at a much higher technology readiness level and are preferable where they are technically feasible. Renewable hydrogen could have a role in the heavy-duty land transport sectors, such as freight, regional and intercity buses, and rail. The priority for these sectors is to electrify where technically feasible, as outlined in Ireland's Road Haulage Strategy 2022-2031[39]. However, depending on how battery electric technology develops in the coming years for these end-uses, full electrification may remain a challenge for some heavy duty, long-range applications. Heavy goods vehicles account for 15% of transport energy demand in Ireland today, but this is projected to rise to 30% by 2050 and must transition to zero emission alternatives. Renewable hydrogen presents a potential decarbonisation alternative for these sectors if and where battery-electric vehicle technology proves to not be technically feasible.

Electric-power trains will be the primary means to decarbonise the commuter rail sector and plans are underway under the DART+ programme to this effect. Electrification of the rail corridors are likely to prove more cost effective, especially over the distances covered by the Irish rail network. However, hydrogen powered trains could potentially offer a solution along routes where full electrification of the rail corridor is not possible, or where the timelines to deliver the

[38] White Paper on Enterprise 2022-2030 – DETE
[39] Ireland's Road Haulage Strategy 2022-2031

infrastructure to electrify the rail corridor necessitate alternative solutions such as hydrogen propelled trains as an interim solution. Another area where hydrogen powered trains could be considered is as backup to electrified rail, providing resilience to the rail route should an overhead electrical fault occur on a route.

Under European regulations and directives, Ireland will have specific targets for the deployment of renewable hydrogen in the transport sector by 2030. The provisional agreement on the Renewable Energy Directive proposes a target of 1% of Ireland's transport energy to be in the form of renewable hydrogen with an additional 5.5% being either renewable hydrogen or a form of advanced biofuel by 2030. The forthcoming EU Alternative Fuels Infrastructure Regulation, which is expected to enter fully into force in early Q1 2024, will also require Ireland to deliver a minimum number of hydrogen refuelling stations to be constructed on the island along the TEN-T network by 2030. In line with the expected requirements of the regulation, the Department of Transport will also undertake public consultation to inform an update of the Government's current National Policy Framework for Alternative Fuel Infrastructure 2017-2030, that will include further consideration of the role for hydrogen in transport, relative to other renewable and zero-emission alternatives.

Case Study

Hydrogen Bus Trials

In July 2021, three of the world's first double-decker hydrogen fuel-cell-electric buses were purchased by the National Transport Authority (NTA) and brought into service on Bus Eireann's route between Dublin and Ratoath, Co Meath. The three buses collectively completed over 40,000 km by the end of 2021, using just over 2,300 kg of hydrogen in the fuel cells to charge the main electric drivetrain batteries. Conventional diesel buses would have consumed approximately 13,000 litres of diesel to complete the same mileage on the same routes. This equates to approximately 34,000 kgCO_2 of avoided emissions by the three buses in less than five months. During the pilot phase, the technology has proven to be extremely reliable, and the hydrogen consumption has remained within the expected consumption profile. Passenger and driver feedback have also been very positive with respect to the environmental benefits, lower noise levels, safety and performance of the buses.

Figure 6: Launch of National Transport Authority's Hydrogen Bus Trials

Aviation

In 2019, Aviation represented 22% of Ireland's transport energy demand[40] with the sector predominantly using imported hydrocarbon-based jet fuel. Sustainable Aviation Fuels (SAFs) are seen as the most likely pathway to decarbonising emissions in this sector in the long-term. Today, the volumes of SAFs consumed in the aviation sector is minimal, with those being produced primarily derived from bio-based resources. The benefits of SAFs are that they can offer a direct substitute/drop-in fuel replacement for fossil jet fuel used today. Given the limited availability of these resources, in future the sector will need to look to alternative ways to produce SAFs. One such approach is to produce fuels such as e-methanol or e-kerosene. These fuels can be created through combining renewable hydrogen with carbon dioxide through a refining process and are commonly referred to as e-SAFs. Given our considerable renewable resources, particularly offshore wind, Ireland is well positioned to produce the renewable hydrogen needed to become a large-scale producer of e-SAFs in the future. A reliable source of green carbon dioxide is also needed to support this production process. This could potentially be supplied in several ways, including carbon capture of industrial processes and large energy users, direct air capture or from biomethane plants by capturing carbon dioxide emitted through the purification process of biogas to biomethane. As set out in the Long-Term Strategy for Reducing Greenhouse Gas Emissions, the carbon dioxide needs for SAFs will be considered further under the future Carbon Capture and Storage strategy.

The European Council and the European Parliament reached a provisional political agreement on the 'Fit for 55' RefuelEU Aviation file on 25th April 2023. This will set out minimum targets for the share of SAFs in the EU aviation sector of 2% by 2025, 6% by 2030 and ultimately rising to 70% by 2050 with more interim targets in between. Of this, at least 0.7% by 2030 are required

[40] Transport | Energy Statistics In Ireland | SEAI

to be produced from e-SAFs, increasing to 35% by 2050[41]. There is also a flexibility mechanism until 2035, where fuel suppliers may supply these targets as a weighted average across European airports meaning these volumes may not be required at Irish airports during this transition period depending on how the market develops.

The direct use of hydrogen may also offer a solution in some of the aviation sector. However, further technological developments are required to happen in this space. Airbus is currently working on developing commercial planes which could carry up to 200 passengers over distances of 2000 km or more[42]. These are being targeted for market entry from 2035. If delivered, this could provide a pure hydrogen solution for short to medium haul commercial flights also.

Renewable hydrogen is expected to play a significant role in the aviation sector from the early 2030s and will scale up rapidly thereafter with the greater use of e-SAFs. Ireland is well positioned to produce renewable hydrogen to meet the needs of the aviation sector, however, SAFs will be a competitive international market. To better understand the competitiveness of indigenously produced hydrogen in this sector, further consideration of the likely cost of renewable hydrogen produced in Ireland compared to other countries progressing export strategies for renewable hydrogen is needed. Ireland does not have significant expertise today in the production of SAFs with most of our aviation fuels imported from other jurisdictions. A better understanding of our ability to support the full supply chain needed to produce SAFs including skills as well as other feedstock inputs such as carbon dioxide is needed to better understand this market opportunity.

Maritime

While it is likely that some smaller scale and domestic maritime needs will be able to be met using battery electric solutions, large scale shipping, like aviation, will require the use of hydrogen derived low carbon synthetic fuels, such as liquified hydrogen, ammonia, and methanol. Although the maritime sector demand in Ireland is significantly smaller than the aviation sector it could play a key role in terms of potential hydrogen exports to international markets or future supply of marine bunkering to other jurisdictions. Under the forthcoming 'Fit for 55' FuelEU Maritime EU regulation, the maritime sector (vessels above 5,000GT) is required to achieve a 2% reduction in emissions from 2025, rising to 80% by 2050[43]. Hydrogen derived fuels are expected to play a significant role in achieving these objectives with RFNBOs applied to the sector receiving a double credit up to 2033 and sub target of 2% RFNBOs being introduced in 2034, subject to an assessment by the European Commission. The extension of the EU Emissions Trading System to include the maritime sector will also have a significant impact on the carbon price of the fossil fuels currently utilised in shipping and will serve to help in reducing the price gap between Green and Black fuels. The cumulative impacts of the maritime related files in the "Fit for 55 package" will have a role to play in making alternative fuels such as hydrogen derived fuels a more attractive prospect for ship owners from a business case perspective. Like aviation fuels, Ireland does not have significant expertise in the production of hydrogen derived carriers currently and work is needed to better understand the potential market opportunity, and what would be required to enable Ireland to deliver on this opportunity.

[41] EUR-Lex – 52021PC0561 – EN – EUR-Lex (europa.eu)
[42] ZEROe – Zero emission – Airbus
[43] EUR-Lex – 52021PC0562 – EN – EUR-Lex (europa.eu)

Non-Energy End-Uses

In addition to being an energy carrier, hydrogen can be used for chemical feedstocks and the development of certain non-energy products. Ammonia production represents a significant percentage of current global hydrogen usage, predominately as the key feedstock for fertiliser production. At present, Ireland's fertiliser demand is met entirely through imports. Renewable hydrogen could potentially play a role in reducing Ireland's dependence on imported chemical fertilisers produced from fossil fuels and help the move towards lower emission and organic alternatives.

It is not clear at this stage if there is a viable opportunity in Ireland for fertiliser indigenously produced from renewable hydrogen. Overall, the primary focus of developing a hydrogen sector in Ireland is to deliver decarbonisation in the energy sector and enhance energy security. Though they are not the core focus of this strategy, other non-energy end-uses may arise as the hydrogen economy develops and can be assessed through market feasibility studies and explored further if a strategic opportunity is identified.

Exports

Our long-term ambition is to develop 20 GW of offshore renewable energy production by 2040 and at least 37 GW by 2050. This equates to roughly 150 TWh per annum and coupled with onshore renewables will be more than our indigenous needs. Ireland's theoretical offshore resource potential alone is estimated at 2,852 TWh[44]. While not all of this will be achievable, it shows the potential scale of the export opportunity that may exist in the long-term.

Ireland's current hydrogen production capacity is effectively zero and developing the scale of renewable generation required to support an export market will take time. Ireland is also significantly ramping up our renewable ambitions to support an 80% renewable electricity target for 2030 meaning there is also competing needs for these renewables in the short term. Deploying more offshore wind, either floating or fixed foundations, will be essential to scaling up hydrogen production in Ireland. Floating wind technology is still under development and anticipated to be commercially deployed from c. 2030 onwards. Floating offshore wind will allow Ireland to harness its full potential from our seas and produce sufficient renewables to meet both our domestic needs and potential export markets. Therefore, hydrogen exports are not envisioned to have a significant role as a form of hydrogen demand until at least the mid-2030s.

Additionally, while Ireland has significant potential to produce hydrogen for export in the long-term, numerous other countries are also exploring opportunities to export renewable hydrogen. Further work is needed to better assess the competitiveness of Irish produced renewable hydrogen compared to international price benchmarks and the benefits that a future hydrogen export market could deliver to the Irish economy.

Hydrogen Blending Through the Gas Network

Existing gas network end-users could operate on a blend of hydrogen and natural gas whilst retaining their existing supply routes and end user equipment. Through the use of a guarantee of origin scheme, certain end users could purchase the renewable hydrogen gaseous blends, potentially offering an early commercial market for renewable hydrogen producers.

44 7338cf63-e174-4932-8c61-6b840e447f3d.pdf (www.gov.ie)

As part of Action 169 of the Government's Climate Action Plan (CAP) 2021, Gas Networks Ireland completed a technical and safety feasibility study on 'Injecting renewable hydrogen blends into Ireland's gas network'. The findings from the study indicated that it will be both safe and feasible to utilise the existing gas network infrastructure to transport blends of hydrogen with natural gas and 100% hydrogen on the gas network with some modifications.

Ireland's gas distribution network is compatible with pure hydrogen transportation with only some modifications required. Gas Networks Ireland will be undertaking a programme of materials testing for around 50% of Transmission pipelines in order to continue to operate the gas network with pressures similar to those used today, when transporting hydrogen blends above 10% and for 100% hydrogen.

A 20% blend of hydrogen by volume for example, a level beyond which many end user appliances are expected to have difficulties operating under, would only deliver around 7% carbon emissions savings. While blending may offer an initial demand sink in the short term, it can only be supported if it can prove to be a transitional step to the development of pure hydrogen transportation and end uses. Blending may also have challenges in terms of user acceptance and associated costs with maintaining gas quality. More details on these aspects are discussed in Chapter 4.

Overall, blending is not seen as a high priority end-use for renewable hydrogen. Blending could play an enabling role however as a "supply of last resort", where there is excess production or as a transport and storage buffer in the absence of dedicated hydrogen infrastructure. Blending into the gas network in these instances may offer a solution to improve the overall efficiency of the value chain and reduce overall production costs.

Table 7: Summary of hydrogen end uses envisioned

End Uses	Priority Order	Role Envisioned	Alternative Technologies	Likely market entry timeframe
Existing hydrogen end users	1	Renewable hydrogen to replace the niche fossil fuel-based hydrogen uses currently in Ireland	N/A	2025-2030
Flexible Power Generation and long duration energy storage	2	Zero carbon flexible backup generation and long duration energy, enabling high penetrations of variable renewables and system security	Bioenergy-based generation, CCS enabled natural gas generation, system flexibilities (demand side management. etc.)	2030-2035
Integrated Energy Parks for Large Energy Users	3	As a backup to renewable electricity/ grid electricity to meet high reliability requirements	Bioenergy-based generation, battery storage	2025-2030
Industrial heat and processing	4	Supply for high temperature heating and other processing needs	Bioenergy-based generation, CCS enabled natural gas combustion, electrification	2030-2035
Aviation	5	As a zero carbon synthetic fuel alternative to jet fuel	Bio-based synthetic aviation fuels	2035-2040
Maritime	6	As a zero carbon fuel such as ammonia for international shipping	Liquid bio-based fuels, battery electric	2035-2040
Road and rail transport	7	Road movements requiring long duty cycles and longer distances. Rail where electrification not feasible/or as a backup	Battery electric, bio-CNG, biofuels, modal shift	2025-2030
New non-energy uses	8	Fertiliser production and other chemical processes not currently produced in Ireland	Import from third countries	N/A
Exports	9	Production in excess of domestic needs	N/A	2035-2040
Blending	10	Mitigation solution where excess production/end-use variability exists	Sufficient hydrogen storage and transportation	2025-2030
Commercial and residential heating	11	Niche areas where electrification, district heating not feasible	Heat pumps, district heating, biomass boilers, biomethane	2035-2040

3.3 Indicative 2050 Hydrogen Demand Projections

Our energy system is set to undergo transformative changes over the coming decades. Electricity today represents about 20% of our overall energy demand, but this is set to more than double by 2050 with the increased electrification of heat and transport, resulting in an energy system where more than half of final energy demand is electric. Energy efficiency will also play a major part in reducing our energy intensity per capita, but some of this will be counteracted with Ireland's increasing population and economic growth projections over the coming years. It is envisioned renewable gases such as hydrogen will mainly play a role in the remainder of our energy system where electrification is not possible. Significant uncertainty remains in respect to the future costs of production of renewable hydrogen and how it will sit alongside competing decarbonisation solutions for certain sectors such as bioenergy and potentially abated fossil fuels with carbon capture.

The below table sets out indicative hydrogen demand projections for 2050, based on possible market shares that might be achieved following electrification and energy efficiency measures. There figures are based on a high-level desktop assessment, on the back of previous modelling which was done to support the Climate Action Plan 2023. An in-depth modelling exercise was not undertaken. Significant uncertainty exists around these figures given renewable hydrogens is a nascent technology, the current knowledge gaps which require further assessment and in the absence of more detailed analysis to quantify the needs of a 2050 net zero integrated energy system including the likely volumes of renewable hydrogen required to supply this. Further work should be progressed after the publication of this strategy to better analyse and refine these figures.

Table 8: Indicative Outlook for Renewable hydrogen across end use sectors in Ireland for 2050

2050 End Use Sector	Estimated Hydrogen Demand (TWh)		Electricity required to meet demand (TWh)		Rationale
	Low Range	High Range	Low Range	High Range	
Flexible Power Generation or Integrated Energy Parks for Large Energy Users	3.6	13.3	5.1	19.0	Between 5-15% of power sector is estimated to be met by dispatchable zero emission sources by 2050. Hydrogen competes with bioenergy solutions and potentially abated natural gas for this market share.
Commercial and Residential	0	1.5	0.0	2.1	Electrification and district heating are the primary supply sources for this sector. Hydrogen plays a niche role, if any, as a back-up fuel supply. It competes with other technology options such as solid biomass/biogas for this niche share.
Industry and processing	0	14.9	0.0	21.3	Between 33-50% of industrial demand is electrified. The vast majority of Ireland's indigenous bioenergy resources (estimated at 11.2 TWh as per National Heat Study) supply this sector also. The low scenario also assumes an additional 5 TWh of abated natural gas is retained for use in industries such as cement.

continued

2050 End Use Sector	Estimated Hydrogen Demand (TWh)		Electricity required to meet demand (TWh)		Rationale
	Low Range	High Range	Low Range	High Range	
Road and Rail transport	1	9.3	1.4	13.3	The high scenario assumes up to half of heavy duty demand is met by hydrogen, whilst passenger is fully electrified. The low scenario assumes further advances in battery electric technology result in delivery the majority of this sector's needs.
Total Domestic Energy Needs	4.6	39	6.6	55.7	
Aviation	13	26	26.0	52.0	The Aviation industry is predicted to grow by 3.6% per annum to 2050[45]. The lower scenario assumes 35% of this demand is met by e-SAFs as per the ReFuelEU Aviation mandate. The higher scenario assumes the higher mandate for SAFs of 70% are all delivered by e-SAFs.
Maritime	2.2	2.6	4.4	5.2	The maritime sector is predicted to grow by 3.6%per annum to 2050[46]. The IEAs Net Zero by 2050 study estimated that 63% of this will be met by hydrogen-based fuels[47] whilst IRENAs decarbonising shipping estimates it closer to 74%[48]. These are used to set the high and low scenario values for shipping.
Other Potential Non-energy Uses	0	7	0.0	14.0	High level working assumption in the absence of further market analysis
Total needs including non-domestic energy uses	19.8	74.6	28.3	106.6	

45 Aviation – Analysis – IEA
46 Global Freight Demand to Triple by 2050 (maritime-executive.com)
47 Net Zero by 2050 – A Roadmap for the Global Energy Sector (windows.net)
48 A pathway to decarbonise the shipping sector by 2050 (irena.org)

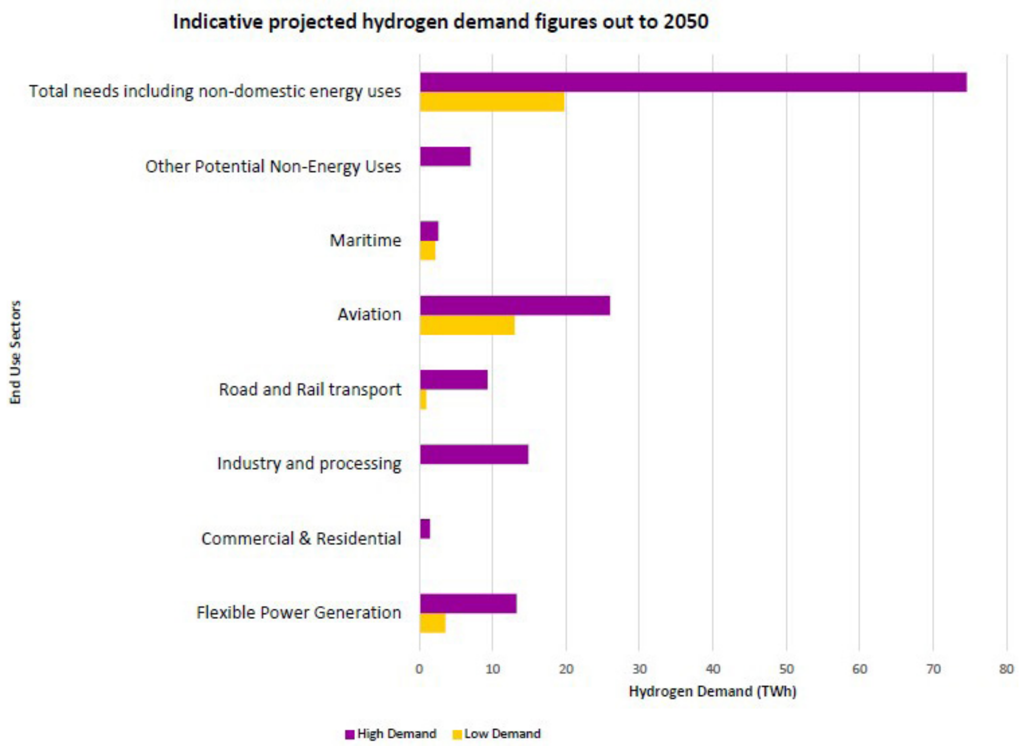


Figure 7: Graphical representation of indicative projected hydrogen demand figures out to 2050

Summary of main assumptions used to develop these figures:

- Final Energy Demand for domestic sectors were taken from scenarios developed by MaREI to support the Sectoral Carbon Budgets Development in 2022[49].
- Reduced Sectoral CB (HL) was chosen as lower Final Energy Demand Scenario to reflect a net zero scenario with greater focus on high electrification and energy efficiency.
- Reduced Sectoral CB (TO) chosen as higher Final Energy Demand Scenario to reflect a net zero scenario with more open approach to a mix of technologies including hydrogen.
- International Aviation and Shipping final energy demand was taken separately based on international growth rate predictions as per the sources in the Table below.
- Non-Energy Uses, including the production of chemicals such as ammonia for use in Ireland as opposed importing them, is a high-level assumption and will need to be better refined in future assessments.
- It is assumed that domestic energy end uses are in the form of gaseous hydrogen and the efficiency of the electrolysis process is 70%.
- For non-domestic energy uses, it is assumed that these end uses are in the form of a hydrogen derivative such as ammonia, e-methanol etc. It is assumed that an additional 20% energy loss occurs in the conversion from gaseous hydrogen to these fuels.
- Additional rationale per subsector can be found in the Table.

[49] EPMG Energy Scenarios – https://epmg.netlify.app/tim-carbon-budgets-2022/results/overview/emissions-and-cost

Actions

1. Develop a roadmap to bring net zero dispatchable power solutions to market by 2030, to support the delivery of a near net zero power system by 2035
2. Undertake further work to assess the role that integrated energy parks could play in our future energy system, including their potential benefits and the possible barriers (market, legal or other) that may exist
3. Publish the draft National Policy Framework on Alternative Fuels Infrastructure, and support the roll-out of hydrogen powered heavy duty vehicles and refuelling infrastructure in line with EU requirements set out in the recast Renewable Energy Directive and Alternative Fuel Infrastructure Regulation
4. Through the development of the National Industrial Strategy for Offshore Wind, assess the feasible potential for end uses such as eFuels, decarbonised manufacturing and export of Hydrogen and its derivatives

4 Transportation, Storage, and Infrastructure

Key Messages

- Initial hydrogen applications are likely to utilise compressed tankering solutions. As production expands, hydrogen pipelines are envisioned to become the dominant transportation option.
- Hydrogen infrastructure is expected to roll out initially across several regional clusters where production, high priority demand and large-scale storage are co-located.
- The expansion and linking of these clusters into a national hydrogen network will be key to creating a liquid mature hydrogen market. Where feasible, repurposing existing natural gas pipeline infrastructure to hydrogen is favourable.
- Work to date has shown promising results in terms of the technical capability of the gas network to transport hydrogen blends up to 100%. More work is needed to better understand the costs, phasing of transition and potential impacts for existing network users.
- Long duration storage is essential to the future cost competitiveness and price resilience of hydrogen. Geological storage solutions will be needed to support this.
- Networks and storage infrastructure, as well as interconnection import/export routes, will play a key role in ensuring security and price resilience of supply.
- Commercial ports will play an important role in facilitating the establishment of a hydrogen economy.
- Long term integrated planning is essential to identify the long-term infrastructure needs to deliver an integrated net zero energy system.

4.1 Hydrogen Transportation

Hydrogen can be transported through compressed tankers, pipelines or in liquid form through conversion to one of several hydrogen derived liquid energy carriers such as ammonia. Each of these methods have their own benefits and challenges and their suitability to end-use applications depend on the locations of production and volumes of hydrogen demand. The table below summarises each. The distances and scales outlined are for generic illustrative purposes and may differ for specific applications.

Table 9: Summary of hydrogen transportation options

#	Option	Key characteristics
1	**Hydrogen tankers**	• Effective for decentralised small-scale applications • Quick to mobilise and flexibility to supply multiple locations. • Safety considerations due to cumulative impacts of increased road transportation of hazardous goods • Expensive and energy intensive to transport for larger applications or long distances • Existing safety regulations in place
2	**Dedicated pipelines**	• Suitable for centralised larger scale gaseous demand uses • Higher upfront investment costs and lower supply flexibility • Overall lower cost of transporting larger volumes of hydrogen • Repurposing of existing gas network assets can offer further cost savings • Safety and regulatory frameworks will take time to establish • More energy efficient and safe method of transportation at scale
3	**Hydrogen derived carriers**	• Greater energy density of the energy carrier makes transporting via tankers/ shipping more viable • Greater energy density of the energy carrier makes large scale transportation via tankers / shipping more viable • Greater flexibility to supply multiple locations • Additional costs and energy losses to convert from gaseous hydrogen to hydrogen derived fuel (c. 15% of total cost for ammonia, higher for other hydrogen derivatives). Further costs and losses if converting back to gaseous hydrogen for end use application • Further assessment of safety impacts and regulatory regimes needed to ensure risks of transportation are fully understood • Certain applications for renewable hydrogen may be in the form of hydrogen derivatives (e.g., Aviation, Shipping, Chemicals industry). Where the end use is not gaseous hydrogen, transportation as a hydrogen derivative is efficient • Well suited to international hydrogen exports via shipping where pipeline infrastructure may not exist, or the distances involved may prove cost prohibitive

Compressed Tankers via Road/Rail

Compressed tankers are well suited to small scale distributed hydrogen applications such as heavy-duty road transport. Transporting and storing hydrogen by compressed tankers is a proven business model and therefore likely to play a prevalent role during the early years. The capital cost of investment in these technologies is lower than that of alternative infrastructure investments such as pipelines. Compressed tankers also offer a certain degree of flexibility as they can be redeployed to different locations reducing the risk of stranded assets.

However, compressed tankers are an expensive method, relatively speaking, of transporting large volumes of hydrogen, with overall lifetime cost estimates 7-8 times more expensive compared to pipelines[50]. Road transportation of tankers would also see increased truck movements carrying highly compressed gaseous fuels. The cumulative traffic, safety, and emissions implications of this also make it less suited for transporting larger volumes.

Dedicated Pipelines

Dedicated hydrogen pipelines allow significantly higher transfer volumes of hydrogen. Today there are already around 5000km of hydrogen pipelines worldwide[51]. Once sufficient demand exists, hydrogen pipelines are expected to be the cheapest method of transporting renewable hydrogen on land. The European Hydrogen Backbone initiative estimates the cost to transport hydrogen over 1000km would be between €0.11 – €0.21 per kg of hydrogen transported[52]. This is relatively low compared to alternative transport methods and would not have a major impact on the overall purchase price of hydrogen.

Currently, there is no regulatory or safety framework for the transportation of pure hydrogen via pipelines in Ireland. The Commission for Regulation of Utilities (CRU) are the national body who undertake this role for natural gas today. It is understood that blends of hydrogen are within the remit of this existing regulatory and safety regime. However, a new framework will need to be established for pure hydrogen transportation applications. A statutory body will need to be assigned to develop and oversee this.

Hydrogen pipelines are significant capital projects, requiring large investment and long lead times for delivery. Once operational, they have a long asset life expectancy. The business case for investment in these projects requires reasonable certainty in respect to future demand. At this early stage, it is difficult to project this demand with certainty and this could make investment in pipeline assets more challenging in the initial years.

It is projected that repurposing existing natural gas pipeline infrastructure can be done at a fraction of the cost of building new pipelines. The European Hydrogen Backbone study estimates the cost of repurposing at 10-35% the cost of building a new hydrogen pipeline[53]. In principle, it makes sense to repurpose existing pipeline assets rather than construct new ones. Repurposed pipelines are also less disruptive as they have already gone through the necessary consent

50 BNEF Long Form Template (Grid) (bloomberglp.com)
51 EU hydrogen policy (europa.eu)
52 The European Hydrogen Backbone (EHB) initiative | EHB European Hydrogen Backbone
53 The European Hydrogen Backbone (EHB) initiative | EHB European Hydrogen Backbone

processes and have been constructed. However, consideration must be given to the continuity of supply to existing natural gas end-users when doing so. Regulatory guidance and oversight will be required to manage potential impacts for consumers during any network transition.

As part of Action 169 of the Government's Climate Action Plan (CAP) 2021, Gas Networks Ireland completed a technical and safety feasibility study on 'Injecting renewable hydrogen blends into Ireland's gas network'. The findings from the study indicated that it will be both safe and feasible to utilise the existing gas network infrastructure to transport blends of hydrogen with natural gas and 100% hydrogen on the gas network with some modifications.

Ireland's gas distribution network is compatible with pure hydrogen transportation with only some modifications required. Gas Networks Ireland will be undertaking a programme of materials testing for around 50% of Transmission pipelines in order to continue to operate the gas network with pressures similar to those used today, when transporting hydrogen blends above 10% and for 100% hydrogen. Further research in this area is vital to continue to prove compatibility in high-pressure transmission, other end use sectors and pure hydrogen compatibility.

Hydrogen Derived Carriers

Gaseous hydrogen does not have sufficient energy density for certain end-uses such as shipping and aviation. Liquefaction of hydrogen is both costly and difficult, requiring the gas to be brought to below minus 253°C and stored in specialised pressure vessels. Hydrogen based synthetic carriers can offer a cost-effective alternative. Examples of this include ammonia, e-methanol, e-kerosene, and liquid organic hydrogen compounds (LOHC). Ammonia achieves a liquid state at minus 33°C and has an energy density of 1.5 times that of liquid hydrogen, while methanol is liquid at room temperature with an energy density two times greater than liquid hydrogen[54]. Additionally, carriers such as ammonia already have well established supply chains internationally today as it is a key feedstock for fertiliser production amongst other things.

Hydrogen derived carriers can be stored and transported more efficiently than gaseous hydrogen. However, there is an energy cost to covert to and from gaseous hydrogen, estimated at around 15% of the total cost of production for ammonia[55]. This cost is likely to be higher for many of the other hydrogen derivatives options, with further costs and energy losses required to then convert back to gaseous hydrogen for end-use applications. Therefore, while hydrogen derived carriers can play an important role, it is likely that this will be concentrated to areas where pipeline transportation is not viable, or where the end-use of renewable hydrogen is in the form of a hydrogen derivative, which is likely to be the case in the international aviation and shipping sectors. In these scenarios, no additional energy losses would be directly associated with transportation.

[54] Hydrogen transportation: three well-known energy carriers compared – Demaco Holland B.V. (demaco-cryogenics.com)

[55] Global Hydrogen Review 2022 (windows.net)

Private Wires

The central legislation governing nearly all facets of the electricity sector in Ireland is the Electricity Regulation Act, 1999(ERA).

Currently, it is preferred that electricity generation be connected to the national electricity grid in the first instance. Section 34 of the ERA outlines the terms for connections to and use of the Transmission and Distribution electricity systems.

Separately, and in compliance with EU legislation, Section 37(1) of the ERA allows for the construction of direct lines in circumstances where either an applicant has been refused a connection to the national grid due to a lack of capacity, or CRU has otherwise determined as a result of a connection dispute that a direct line be built by a developer, in accordance with Section 34(6). A direct line is defined by the ERA to be 'an electric line which is used or is to be used to carry electricity for the purpose of supply and the construction of which line is permitted under Section 37'.

Where hydrogen is being produced in direct proximity to a renewable energy source, in some circumstances it may be more efficient to allow a direct line between the production source to the electrolyser, particularly where the renewable energy is not anticipated to have an end-use in the electricity sector. A public consultation will take place this year in relation to private wires and the outcomes of this will inform future policy changes in this space.

Electricity Network Development and Enabling Offshore Renewable Energy Development

The development of renewable hydrogen will also drive the need for significant expansion in renewable electricity sources. In some instances, renewable electricity may be co-located with production sources to reduce the overall impacts for the electricity grid. However, grid reinforcement will also be required. It is important that this is identified and planned for as early as possible with the electricity system operators, EirGrid and ESB Networks, to ensure no infrastructure bottlenecks arise.

4.2 Hydrogen Storage

Hydrogen storage will play an important role in the future energy system, firstly to balance fluctuations in supply from variable renewables and seasonality changes in end user demand, and secondly providing energy security in case of unforeseen supply disruptions and helping to reduce any related price volatility. Some of the likely hydrogen storage solutions are listed in the Table below.

Table 10: Summary of hydrogen storage options

#	Storage Method	Key characteristics
1	**Compressed tankers**	• Suitable for decentralised small-scale applications such as buffer storage within end user sites • Can be deployed quickly and offers flexibility • Existing safety framework in place
2	**Line pack**	• More suited as a network operator flexibility solution, providing hours of storage in emergency situations by reducing network pressures • As hydrogen is a lower density molecule, the ability to line pack hydrogen is one third that of natural gas and limited to the volumes of hydrogen stored within the network
3	**Geological storage solutions**	• There are several geological storage solutions which could offer a long duration storage solution for renewable hydrogen including salt caverns, depleted gas fields, aquifers, and lined rock caverns • Geological storage solutions offer the most promising and least cost solution to the long durational storage of energy needed to support a future hydrogen economy • Safety and regulatory frameworks to allow geological storage of hydrogen is not yet in place • Location is dependent on geographic availability.
5	**Hydrogen derived carrier storage**	• Conversion costs and losses associated with the production of the hydrogen derived fuel can make this less economical compared to geological storage solutions • Due to the high energy density of the fuel, feasible to store as a long duration energy carrier in bunker/tank solutions • Safety regimes required to ensure any risks of storing energy carriers such as ammonia are fully understood • A cost competitive solution for large scale storage if geological storage is not possible or where the end use is in the form of a hydrogen derivative such as in the maritime and aviation sectors • May also offer a solution in terms of strengthening energy security as a strategic storage option. In such instances, due to the infrequent nature of its usage the efficiency losses in producing the hydrogen derivative are less important • Location is not bound by geography

Hydrogen's ability to act as a long duration store of renewable energy is one of its key strategic attributes. Ireland will require long duration seasonal storage to support future energy security and resilience of supply needs. The exact volumes of how much hydrogen will be required to be stored is still uncertain. However, from an energy security perspective the market currently stores around 90 days of fuel reserves in the form of gaseous or liquid energy carriers. The majority of this storage capacity is rarely called upon however, with much smaller volumes needed to meet the typical day to day and seasonal variances in a typical year. One of the main reasons long duration storage volumes will be required is to manage variability in renewable energy sources such as "Dunkelflaute" events or sustained periods of low pressure resulting in low wind outputs. Analysis by the university of Delft found that these events typically occurred between 2-10 times per annum, lasting up to 24 hours on average[56]. Some storage volumes will also be required to support divergence between end user demand patterns and production, including potential demand seasonality in some sectors. However, the actual quantities needed will be dependent on many factors including the associated costs of storage. Further analysis is needed to better determine the precise storage quantities required as part of a wider study assessing the needs of a net zero integrated energy system. In the absence of this work, the below table outlines possible hydrogen storage volumes required to deliver both two weeks and 90 days of storage based on the 2050 indicative demand figures presented in Section 3.

Table 11: Indicative Hydrogen Storage Needs for 2050 Demand estimates

Storage Needs (TWh)	14 Days Storage Requirement		90 Days Storage Requirement	
	Low	High	Low	High
Storage for domestic gaseous energy needs	0.2	1.5	1.1	9.6
Storage for Hydrogen Derivative needs	0.6	1.4	3.8	8.8
Total Hydrogen Storage Needs	**0.8**	**2.9**	**4.9**	**18.4**

To deliver this scale of storage capacity, some form of geological storage is likely to be required. Different geological storage solutions have different characteristics, whilst some are at a higher technology readiness level than others. The Table below from the IEA summarises the characteristics of the different underground hydrogen storage solutions.

[56] A Brief Climatology of Dunkelflaute Events over and Surrounding the North and Baltic Sea Areas (tudelft.nl)

Characteristics of hydrogen underground storage types

	Salt cavern	Depleted gas field	Aquifer	Lined hard rock cavern
Specific investment	Medium	Low	Low	High
Levelised cost of storage	Low	Medium	Medium	Medium
Cushion gas*	25-35%	45-60%	50-70%	10-20%
Capacity	Medium	Large	Large	Small
Annual cycles	Multiple	Few	Few	Multiple
Geographic availability	Limited	Variable	Variable	Abundant**

*Cushion gas is the volume of gas required as a permanent inventory in a storage facility. Its goal is to maintain sufficient pressure in the storage to meet withdrawal demands at a high rate, even at low storage levels.
**Igneous or metamorphic rock.

Figure 8: Characteristics of hydrogen underground storage types (Source: IEA[57])

The hydrogen salt storage assessment project is a research project, funded by SEAI with the Geological Survey Ireland, being delivered by SLR Consulting Ltd in partnership with Illmatic Energy. The project aims to assess the hydrogen storage potential within manmade salt caverns off the coast of Ireland. Early findings of the study are promising with 271 potential caverns of suitable geology identified off the east coast in the greater Dublin area alone, each of which could deliver in the region of 0.1 TWh of hydrogen storage, or 27 TWh cumulatively. The next phase of the project will continue to assess further areas, specifically the Celtic Sea Basins to the south, Irish Sea Basins to the east and basins on the Atlantic Margin to the west[58]. Ireland also has one depleted gas field located in Kinsale, co. Cork which is believed to have a capacity of up to 7 TWh of storage[59]. Based on this information, Ireland is not expected to have a shortage of suitable geological storage options which could support the long duration storage of renewable hydrogen.

However, the geological storage of hydrogen also needs to be considered in a wider strategic context of what alternative uses may be needed for these strategic assets (e.g., natural gas storage or carbon capture and storage), what are the environmental impacts of developing them and how best to ensure this can all be managed in a strategic and sustainable way. A key action out of this strategy will be to look in more detail at the future needs for geological storage in Ireland and from

57 Global Hydrogen Review 2022 – Analysis - IEA
58 Home – Hydrogen Salt Storage Assessment Project (hyss.ie)
59 H2 Infrastructure Map Europe (h2inframap.eu)

this, work to develop the necessary legislative changes and regulations to enable these facilities to be prospected and ultimately developed. We are aware of both the need for geological storage to be developed over the next 10-15 years as well as the long lead times associated to develop geological storage facilities. We are also aware of some projects currently looking to prospect potential hydrogen storage locations in the short term. Where possible,we will endeavor to enable early projects to progress in tandem to this wider strategic review process.

Hydrogen derivatives may also offer a long duration storage solution, particularly for end-use sectors that are expected to use them, like aviation or shipping. While the cost and additional energy input required mean geological storage is likely to be the more cost-effective solution, depending on the long-term development of these sectors, hydrogen derivatives could play a wider role in energy storage. If large volumes of hydrogen derivatives are stored to meet the needs of these sectors, they could potentially also contribute to Ireland's energy security needs, with the possibility to reconvert to gaseous hydrogen if an unforeseen event occurred which risked Ireland's ability to meet its indigenous hydrogen needs.

4.3 Transitioning Gas Networks to Hydrogen – Blending and Repurposing

Hydrogen Blending

Work to date indicates that it will be possible to blend renewable hydrogen into the gas network and for existing gas network end-users to operate could operate their equipment and appliances on hydrogen blends. Through a guarantee of origin scheme, these end users could purchase the renewable hydrogen gaseous blends, potentially offering an early commercial market for renewable hydrogen producers if it can prove to be a transitional step to the development of pure hydrogen transportation and end uses.

As part of Action 169 of the Government's Climate Action Plan (CAP) 2021, Gas Networks Ireland completed a technical and safety feasibility study on 'Injecting renewable hydrogen blends into Ireland's gas network'. The findings from the study indicated that it will be both safe and feasible to utilise the existing gas network infrastructure to transport blends of hydrogen with natural gas and 100% hydrogen on the gas network with some modifications.

Ireland's gas distribution network is compatible with pure hydrogen transportation with only some minor modifications required. Gas Networks Ireland will be undertaking a programme of materials testing for around 50% of Transmission pipelines in order to continue to operate the gas network with pressures similar to those used today, when transporting hydrogen blends above 10% and up to 100% hydrogen[60].

While these results are promising in proving the technical viability of blending, there are still some concerns that will need to be explored further and addressed to ensure that injecting renewable hydrogen into the gas network is beneficial to the transition of a renewable hydrogen sector in Ireland in the long-term. Firstly, in relation to end user acceptability, a 20% blend of hydrogen by volume is envisioned to be acceptable to most existing end users without any equipment

[60] Hydrogen-Feasibility-Study.pdf (gasnetworks.ie)

modifications, which would deliver around 7% in terms of carbon emissions savings. However, some large energy users such as industrial users will need to have their equipment assessed in more detail to determine if they are technically able to accept the requisite changes in gas quality composition that would occur due to hydrogen blending. It is likely also that some of these end use sectors may only accept a constant blend of hydrogen. This may require significant volumes of buffer hydrogen storage to maintain this constant blend mix. The costs associated with this will need to be understood and compared against other transportation pathways which don't require blending to show there is a benefit.

Blending can offer a way of kick-starting hydrogen production in the absence of pure hydrogen end uses being available, acting as a short-term demand sink. Although blending can be targeted commercially to high priority end uses through the use of a Guarantee of Origin scheme, it does not incentivise these end users to fuel switch directly to pure hydrogen consumption as the hydrogen does not physically flow directly to these end users. That being said, roughly 50% of natural gas demand currently supplies the power sector with another 35% supplying industrial users, of which a large proportion of this would be high temperature heating, correlating well with the high priority end uses set out earlier in the strategy[61]. This is particularly relevant at transmission level.

Longer term, it will be important to also ensure that blending hydrogen into the gas network will not delay the establishment of pure hydrogen end uses. Production and supply routes for future renewable hydrogen end users may also not necessarily match existing natural gas supply routes. A clear network transition plan is needed to take account of these issues. Blending also must not be seen as a reason to extend the lifespan of certain gas network end use sectors such as the domestic sector where the long-term vision is to transition these end users to off network end uses. The network transition plan must also take due consideration of these needs as part of its development.

Overall, Gas Networks Ireland has already undertaken the first steps to proving the networks technical compatibility with hydrogen blends. However, better understanding of the customer acceptance, associated costs, and the pathway for transitioning the network to hydrogen is required. If the United Kingdom decides to blend hydrogen in their natural gas network, it is likely that hydrogen blends will be imported into Ireland via the gas interconnector pipelines (see Section 4.4). The EU Hydrogen and Decarbonised Gas Market Package also requires Member States to be capable of accepting hydrogen blends at interconnection points. This means our gas network will need to be capable of accepting hydrogen blends in any case. Therefore, continued work to assess the technical feasibility and get the networks ready for hydrogen, including localised network trials, is a low regrets action that needs to happen.

Repurposing to Hydrogen Pipelines

The European Hydrogen Backbone study estimates the cost of repurposing at 10-35% compared to the cost of building a new hydrogen pipeline[62]. Repurposed pipelines are also less disruptive as they are already constructed and have gone through the necessary consenting processes. In principle, it makes sense to repurpose existing pipeline assets rather than construct new ones.

[61] GNI-2021-Network-Development-Plan.pdf (gasnetworks.ie)
[62] The European Hydrogen Backbone (EHB) initiative | EHB European Hydrogen Backbone

However, unlike other countries, Ireland's gas network does not have the same level of redundancy or meshing where certain supply routes could be repurposed to hydrogen with little to no impact on existing natural gas consumers, who would still have alternative supply routes available to receive their natural gas. A key consideration in respect to repurposing in an Irish context is how it can be achieved without adversely impacting end-users on the network. For example, repurposing sections of the network may require certain end-users to transition to hydrogen or an alternative energy source. Depending on the costs associated with this fuel switching and the remaining lifespan of the assets, in some instances new dedicated pipelines may prove to be a better solution. The impact of repurposing on gas network tariffs will also need to be considered. The network transition plan must also take account of these facts and set out clearly what parts of the network can be repurposed and when. In addition, clear regulatory oversight and guidance is required to set the rules as to how this transition should be managed, thus ensuring the transition can happen with minimal impact to end consumers.

Case Study

Gas Networks Ireland's Network Innovation Centre

Gas Networks Ireland is working to transition to a decarbonised gas network with renewable gases, such as green hydrogen. To understand the full potential of hydrogen and ensure that the gas network is capable of safely transporting and storing both blended and up to 100% hydrogen into the future, Gas Networks Ireland established its Network Innovation Centre, located in Citywest, Dublin.

Working with University College Dublin's Energy Institute (UCDEI), one of the first innovation projects undertaken was 'Testing of Blends of Hydrogen and Natural Gas' (HyTest). The team tested the operation and performance of gas appliances utilising a range of hydrogen concentrations from 2% to 20% hydrogen.

The research found that householders using natural gas blended with up to 20% hydrogen will not need to make any change to their existing domestic appliances or notice any difference. There was also a substantial emissions reduction obtained by blending hydrogen with natural gas.

Gas Networks Ireland has additional strategic hydrogen research partnerships, including one with Ulster University on hydrogen blend safety and with AMBER on materials compatibility with hydrogen.

Figure 9: Image of Gas Networks Ireland's Network Innovation Centre

4.4 Hydrogen Import and Export Routes

Interconnection with the United Kingdom

Ireland's gas network is connected to Britain through two subsea interconnector pipelines, which supply the majority of Ireland's natural gas demand today. National Gas, the UK's gas transmission system operator, is investigating the potential to have blends of hydrogen flowing through their network from the late 2020s. This means that hydrogen blends may be imported through the interconnectors to Ireland. In addition to this, the South North pipeline connects the gas networks of Ireland and Northern Ireland. This may also provide further opportunities for the trade of renewable hydrogen across the jurisdictions. Close cooperation is also needed between the network operators across the jurisdictions to ensure any potential impacts in terms of gas quality, commercial and regulatory arrangements can be properly assessed, that stakeholders are informed and that any potential mitigation measures are in place to avoid potential risks.

Longer term, our interconnectors with Britain and Northern Ireland could be repurposed to hydrogen, connecting Ireland's hydrogen system in much the same way that our natural gas systems are connected today. The United Kingdom are also working to develop further interconnection with mainland Europe and therefore this offers a potential pathway for pipeline transportation of hydrogen from Ireland to potential export markets in Europe via the UK. Close cooperation and partnership with the UK Government and Northern Ireland Executive in respect of hydrogen developments (including Project Union on hydrogen transmission infrastructure in Britain[63]) will be important to ensure close regulatory alignment and synergies between the two jurisdictions.

[63] Project Union _ Overview 27.8 (nationalgas.com)

The Role of Commercial Ports

The significant role that ports can play in facilitating the development of the Irish offshore renewable energy sector is widely recognised. As set out in the Policy Statement on the facilitation of Offshore Renewable Energy by Commercial Ports in Ireland in 2021[64], a number of port facilities will be required for deployment activity, as well as ongoing operations and maintenance support of offshore renewable energy installations. This will ultimately allow investments that are commercially viable in the long-term progress without undermining the ability of any port to meet its primary obligations in relation to the facilitation of international trade.

Commercial ports also offer several other strategic opportunities in respect of the development of the renewable hydrogen economy. They are generally close to significant energy demand such as power generation, some large industry sectors, and transportation logistic hubs. All of these are potential large sinks for future hydrogen demand. Ports can also play an important role in facilitating the development of any indigenous sustainable aviation and maritime fuels in the future, through using their international transportation logistics links and proximity to industrially zoned lands. Some ports can enable new refining industries which may establish in the vicinity of the port to produce the requisite synthetic fuels (ammonia, e-kerosene etc.) needed for sectors such as maritime and aviation. Finally, ports offer the opportunity to allow large scale exportation of hydrogen-based carriers to the global market, allowing Ireland to become an important player in the global hydrogen market as it develops. In April 2023, the European Clean Hydrogen Alliance published its Learnbook on Hydrogen Supply Corridors[65] setting out likely future hydrogen supply routes for Europe, with the North Seas Hydrogen corridor being the closest route to Ireland. What also makes this supply route of particular interest to Ireland is the focus on the role of ports as part of its hydrogen import strategy from the North Seas. Continued collaboration through the North Seas Energy Cooperation (NSEC) framework will enable Ireland to engage with potential partners on opportunities in this space.

4.5 The Role of Hydrogen in Ensuring Energy Security

There are several factors to consider when assessing Ireland's security of supply, including import dependence, the reliability of supply, energy infrastructure as well as price resilience. The development of an indigenous hydrogen market in Ireland can help to support many of these needs.

In 2021, Ireland imported 77% of its energy supply, up from 72% in 2020[66]. The production of indigenous renewable hydrogen offers a pathway to significantly reduce this, potentially offering a pathway for Ireland to become energy independent.

Today, natural gas provides the reliability and flexibility needed to backup renewables on our power system. As we move to a net zero system, decarbonised dispatchable generation via technologies such as hydrogen will become more critical to delivering a net zero power system. Additionally, hydrogen can offer a solution to many end-use sectors across transport, industry and more, that require the reliability, transportability and energy density offered by natural gas and crude oil products today.

64 1484054d-eab2-4b33-b4c0-8d1619656940.pdf (www.gov.ie)

65 DocsRoom - European Commission (europa.eu)

66 https://www.seai.ie/data-and-insights/seai-statistics/key-publications/national-energy-balance/#comp00006023933e000000bbbe3751

Large scale storage and the development of a national hydrogen network will be important to the realisation of these goals. The natural gas market in Europe today has sufficient storage for roughly 30% of annual consumption. This ensures security of supply, while also helping to improve price resilience through reducing the differential between winter and summer prices, providing greater certainty to the market, and ultimately creating a downward pressure on the price of natural gas. In the future hydrogen market, it is envisioned that significant quantities of hydrogen will also be required to be stored to meet variable production patterns from renewables, coupled with the fact that end user demand will be variable and, in many cases, seasonal.

Pipelines will also offer the safest and most reliable form of hydrogen transportation. Through the development of a national hydrogen network, greater resilience of transportation can be achieved, and cost efficiencies driven by the removal of localised pricing signals, and ultimately by economies of scale through connecting new hydrogen demand sources and enabling the potential interconnection to other jurisdictions.

It will take time for this transition to take place, however. It is anticipated that regional hydrogen demand clusters will develop in the early 2030s and it will be during the mid to late 2030s that the national hydrogen network begins to emerge. On this basis, hydrogen will not deliver significantly to Ireland's energy security needs in the short term. In the interim, natural gas will be required to ensure continued security and resilience of Ireland's energy.

4.6 Hydrogen Infrastructure Roadmap

Before 2030, Ireland's hydrogen sector is envisioned to focus on small scale decentralised applications such as freight, with small scale production driven by early innovators, research, and demonstration projects. Compressed tankering solutions are likely to be the most viable solution for transportation and storage during this time, due to their lower capital investment costs, ability to be deployed quickly and existing safety and regulatory regimes. Some local pipeline networks may emerge directly connecting production and demand sources. Hydrogen blends may also enter the gas network via the interconnectors from the UK.

During the early 2030s, hydrogen demand is anticipated to scale up rapidly with the installation of 2 GW electrolyser capacity from offshore wind. This production is proposed to be targeted towards end-users in a small number of geographically confined areas where renewable production potential, large scale storage and significant demand potential from high priority end users are all in close proximity. Given this fact, it is likely that many of these initial clusters could develop in the vicinity of commercial ports given their role in enabling offshore wind and typical proximity to potential large end users. Further work is needed to determine the optimal locations of these regional clusters, with certain regions such as Cork, Shannon, and Dublin, amongst others, appearing to be well positioned given their offshore renewable potential, ports infrastructure and proximity to industry, power generation and heavy transport end-uses. A decision on the locations of these early hydrogen clusters should be progressed in the early stages of implementation of this strategy.

During the mid-2030s, hydrogen demand is expected to grow as cost of production falls and Ireland moves closer to an integrated net zero energy system. Further clusters will continue to emerge, and existing clusters will grow, creating the need for the development of a national hydrogen network, connecting new high priority end uses along the way. During this time, hydrogen will begin to play a more significant role in Ireland's security of supply.

As the hydrogen network expands and more production is connected, opportunities for exporting renewable hydrogen will begin to emerge. The main routes for this to be delivered are anticipated to be through the repurposing of the existing gas interconnectors to the UK, new interconnection or through shipping via commercial ports in the form of hydrogen derived energy carriers such as ammonia.

Case Study

The Galway Hydrogen Hub

The Galway Hydrogen Hub (GH2) was launched in April 2022 and is supported by SSE Renewables, the Port of Galway, University of Galway, Colas, Bus Eireann, CIE, Galway City Council, Aran Island Ferries and Aer Arann. It has a vision to position Galway as a market leader in the production of green hydrogen for use in transport, industry, and within local communities in the greater Galway region.

In recognising the role that green hydrogen can play in decarbonisation and in supporting Ireland to reach its climate targets, the GH2 coalition intends to develop a flagship pathfinder project at The Port of Galway for the indigenous production and local supply of clean green hydrogen. The Galway Hydrogen Hub is intended as a "proof of concept" project, demonstrating how hydrogen can be produced and used locally as part of an indigenous value chain.

Figure 10: Image from the Launch of the Galway Hydrogen Hub

4.7 The Need for Long-Term Integrated Planning

Infrastructure is key to enabling the scale up and large-scale deployment of cost competitive renewable hydrogen in Ireland. Delivering this requires better integration between renewable spatial planning, electricity, gas and water networks, long-term supply and demand planning as well as identifying and progressing the development of large-scale storage solutions. Hydrogen's role is that of an enabler of a more integrated net zero energy system. As such, future systems planning in this space must ensure clear alignment with Ireland's climate ambitions, energy policy and be applied consistently across all sectors.

Large scale infrastructure requires significant lead times to develop, better consideration of the long-term needs of the system is required to ensure infrastructure needs are determined early to allow sufficient time to consent, finance and build. Though the hydrogen infrastructure roadmap discussed above suggests that large scale hydrogen networks infrastructure will begin to emerge from the mid-2030s, work to identify the infrastructure needs and how existing pipelines can be repurposed while ensuring existing end user needs are managed appropriately, will need to commence much earlier. Similarly for long duration storage, the timelines to deliver such projects will be significant and work is needed in the early years to better identify the potential needs, and ensure the correct signals are in place to enable its delivery.

The need for more integrated long-term systems planning is a key theme emerging throughout this strategy. Further studies to better determine what an integrated net zero energy system looks like and how this can be incorporated into the long-term strategic planning of government policy and infrastructure operators' development plans will be an important area of future work.

Actions

1. Undertake further work to determine the quantities and profile of zero carbon long duration energy storage needed out to 2050, and develop a roadmap as to how it can be delivered
2. Undertake a review of the existing licensing and regulatory regimes relevant to the geological storage of hydrogen, and progress the necessary legislative changes and development of regulatory regimes to facilitate future prospecting and development of underground hydrogen storage solutions
3. Continue work to prove the technical capabilities of the gas network to transport hydrogen through the network and closely work with the network operators in neighbouring jurisdictions in respect to interoperability between the networks
4. Develop a plan for transitioning the gas network to hydrogen overtime, taking due consideration of:
    a. plans to develop a biomethane sector in Ireland,
    b. the prioritisation of end uses set out in the National Hydrogen Strategy and their likely locations where known,
    c. the need to maintain energy security through the transition,
    d. how existing end users can transition from natural gas to hydrogen, or to alternative energy solutions such as electric heating,
    e. the potential use of hydrogen blends during a transition phase, the costs associated and how the transition from blending can occur.

    The plan should look to identify where the network can be repurposed, or where new pipelines may be required and provide detailed costings and a programme of works

6. Progress work to identify and support the development of strategic hydrogen clusters
7. Commence a review of current approaches to energy systems planning and make recommendations to support a more integrated long-term approach to planning across the network operators including electricity, natural gas, hydrogen, and water

5 Safety and Regulation

Key Messages

- Hydrogen safety is essential, and early focus is needed to develop a safety roadmap to delivering the necessary safety frameworks and regulatory regimes across the entire hydrogen value chain.
- The EU Hydrogen and Decarbonised Gas Package sets out the regulatory market rules for scaling up hydrogen and the development of dedicated hydrogen infrastructures. Ireland should adopt the outcomes of this in a timely manner.
- Renewable and low carbon hydrogen will be defined in line with EU regulations, and a certification scheme should be established to reflect these definitions, providing certainty to end users as to the origin and sustainability of their hydrogen.
- Considerations around hydrogen leakage and NOx emissions are already being assessed at European level. Future standards may be developed to mitigate these risks and adopted at a national level.
- There are several gaps in terms regulations, licensing and permitting across the entire hydrogen value chain. A full review is needed to identify these gaps and ultimately implement the required changes to alleviate them.

Delivering on the opportunities identified in this strategy will require clarity on the necessary safety requirements and standards to be in place in addition to a full review of legislative, licensing, safety, regulatory, planning and market frameworks to ensure that they can facilitate the development of Ireland's hydrogen sector and so that any knowledge gaps or barriers can be identified and removed.

This will allow early innovators to proceed with hydrogen projects, as well as providing greater certainty to developers and the market in respect to the standards, quality assurance and safety of hydrogen developed within the Irish market.

Standards and regulatory regimes developed in Ireland must also be done in a manner which is in line with European policy, legislation and considerate of our other international partners as much as possible. This review will be a key part of the work programme to enable the development of Ireland's hydrogen industry.

Hydrogen Safety

The Commission for Regulation of Utilities (CRU) are today responsible for regulating the safe operation of the natural gas market in Ireland, covering aspects associated with transmission, supply, and public awareness. They undertake this role through an established gas safety framework which sets out the requirements for operators to submit a safety case to the CRU which demonstrates safety risks are mitigated to a standard of ALARP (As Low as Reasonably Practicable). The primary objective of this framework is to ensure public safety. Based on current legislation, the safety of blends of hydrogen which enter the natural gas network today are covered under this framework. However, the framework would not cover aspects relating to the transportation of pure hydrogen as this is currently not part of the CRUs legislative remit.

The Health and Safety Authority (HSA) has responsibility for ensuring workers and those affected by a work activity are protected from work related injury and ill health. This role is undertaken under the occupational Safety, Health and Welfare at Work Act 2005.

Under the Chemicals Act, the HSA is one of the Competent Authorities responsible for regulating in respect to the control of major accident hazards involving dangerous substances (COMAH). The HSA also ensures Ireland's compliance with international conventions on transportation of dangerous good by road (ADR).

Based on the current legislation and hazards associated with hydrogen, protection of occupational health and safety in the workplace is addressed under the general duties on employers to risk assess work activities. There is no specific occupational health and safety European or national legislation for hydrogen safety.

In the context of hydrogen storage, the requirements of COMAH legislation are only relevant where the maximum anticipated quantity of hydrogen is greater than 5 tonnes. This is an important consideration in terms of hydrogen refuelling stations, which are envisioned to be one of the early end uses of renewable hydrogen as these facilities will likely fall under this threshold. Given the timelines envisioned, this will likely be one of the first areas to study.

The current occupational health and safety regulations provide a general framework and address hydrogen predominantly on the basis that it is used for industrial applications in specialised niche end-uses. The current regulatory safety regime would not be appropriate for the wide scale roll out and utilisation of hydrogen as a zero-carbon energy carrier across the energy sector. Therefore, consideration must be given to this fact in determining what is an appropriate regulatory framework for ensuring hydrogen safety in Ireland given the future strategic ambitions set out in this strategy. The best way to ensure this is through the development of a hydrogen safety strategy or framework. This should aim to

a. Use previous knowledge and learning developed through the likes of the existing natural gas safety framework where applicable.
b. Ensure best practice and approaches are as consistent as possible across all transportation vectors and end uses, in line with the foreseen risk profiles.
c. Clearly set out the responsible authorities, their roles and responsibilities across the entire risk value chain.
d. Account for the potential use of both hydrogen and hydrogen-based derivatives as a means of transportation and storage.
e. Take consideration of the fact that hydrogen will have both onshore and offshore elements. The CRU through the Petroleum Safety Framework, currently regulates the safety of petroleum exploration and extraction activities in this area. It will be important to ensure that future legislation for offshore hydrogen safety is closely aligned with that of other offshore renewable energy activities.

Given the hydrogen sector is still at an early stage with many standards still under development, it may be more appropriate to develop a hydrogen safety strategy or framework which could initially be applied on a voluntary basis, which would then be used as a test case for early projects to assess its suitability and identify where improvements can be made, before ultimately progressing to establish it as a legally binding regulatory framework.

A work group should be established to progress the development of this safety strategy/framework. This working group should consist of the Commission for Regulation of Utilities, The Department of the Environment, Climate and Communications, The Department of Transport, The National Standards Authority of Ireland (NSAI), Gas Networks Ireland, The Competition and Consumer Protection Commission, The Health and Safety Authority (HSA), the Environmental Protection Agency (EPA), Local Authorities and other representative bodies from industry amongst others.

Hydrogen Market and Regulatory Regimes

As we move forward, hydrogen will become more prevalent in our energy system, with widespread end-uses, requiring networks, large scale storage and imports/exports via interconnection or shipping. To facilitate this transition, it is important that a common approach is applied to areas such as transportation, sustainability, and gas quality, such that Ireland can be a part of an integrated European hydrogen market.

The European Union are currently developing the Hydrogen and Decarbonised Gas Market Package[67]. This Package proposes to amend the current EU gas markets directive and regulation to develop a regulatory framework which enables the deployment of renewable gases, whilst providing clarity on the rules associated with the development of hydrogen infrastructure such as pipelines, terminals, and storage facilities. The current proposals set out rules relating to facilitating access to hydrogen infrastructure, associated tariffs, rules on unbundling from production and supply as well as placeholders to develop common approaches to standards on gas quality and its carbon intensity. Most rules proposed align closely with the regulatory rules in place today which enabled the establishment of the integrated natural gas market in Europe.

As outlined previously, Ireland's key strategic opportunity is in the production of renewable hydrogen to support the achievement of an integrated net zero energy system. However, further clarity is needed to define what is categorised as renewable hydrogen. Ireland will eventually become a part of an integrated European hydrogen market, which is trading renewable and low carbon hydrogen between Member States. Under the Renewable Energy Directive and the Hydrogen and Decarbonised Gas Market package, definitions as to what is deemed to be renewable and low carbon hydrogen are being set out.

There is also recognition of the importance not to stifle early development in the emerging hydrogen sector through over regulation. To this effect, the package has proposed lead in times for many of the key aspects of the package as well as introduced the concept of geographically confined networks where a less stringent ruleset could be applied until the hydrogen market matures sufficiently in certain jurisdictions.

The package is at an advanced stage of negotiations within the EU institutions and a final agreed directive and regulation is likely to be in place by the end of 2023. Once enacted, Ireland shall ensure the relevant regulatory and legislative changes needed are progressed to implement this at a national level. The Commission of Regulation of Utilities is currently responsible for overseeing the implementation of these rules for natural gas today and would be well positioned to develop a national regulatory framework for hydrogen based on these rules.

[67] Hydrogen and decarbonised gas market package (europa.eu)

One other important consideration upon which a decision will be required in the early years of the implementation of this strategy is the role of the hydrogen network operator. Currently, Gas Networks Ireland is the only transmission and distribution network operator of natural gas in Ireland. They would be well positioned to operate a future hydrogen network. National networks such as for natural gas, electricity and in future hydrogen are natural monopolies. However, as geographically confined clusters emerge, other entities may look to be certified as the hydrogen network operators of these localised pipelines. This could result in numerous hydrogen network operators establishing which could have disadvantages in the longer term as a national network emerges. A decision on whether these localised network operators should be allowed to emerge or whether a single national network operator should be appointed will require further thought in the coming years.

Standardisation

There are many existing European and International standards relating to hydrogen in place today and further standards for hydrogen are being developed, including standards relating to the injection and transportation of hydrogen through the existing gas network. Earlier this year, the European Clean Hydrogen Alliance (ECH2A) published a Roadmap on Hydrogen Standardisation, which provides a comprehensive overview of standardisation gaps/priorities and needs along the whole value chain. This roadmap will be taken into account as part of the efforts made in revisions and development of new hydrogen related standards.

The National Standards Authority of Ireland (NSAI), through their Gas Technical Standards Committee (and other relevant Technical Committees), are monitoring and contributing to the development of these standards, as well as ensuring their ultimate adoption as Ireland specific standards. This work is an essential building block to ensuring suitable standards exist across the entire hydrogen value chain. Related European and international standardisation activities (e.g., in the area of net zero energy systems, carbon capture, bioeconomy, and so on), will also be relevant.

Hydrogen quality, hydrogen emissions and guarantee of origin are all topics that will require careful consideration in the Irish context. These topics also form part of the identified priorities and needs along the hydrogen value chain that are being reviewed through standardisation.

With regards to research, development and demonstration (RD&D) activities, the research community is encouraged to engage with the standardisation process as early as possible. This will inform on any gaps and needs to be considered and allow to test the relevance of their results for standardisation. The European Commission has published a code of practice on Standardisation in the European Research Area, which is aimed at higher education institutions, Research and Innovation (R&I) organisations, project partners, policy, and wider stakeholder levels. The code of practice proposes a set of recommendations on how to best identify opportunities and techniques to increase the uptake of R&I results in the single market through standardisation.

Case Study

Developing Ireland's National Hydrogen Standards

Gas Networks Ireland is facilitating the secondment of a Hydrogen Standardisation Expert into NSAI to work on standardisation activities relating to hydrogen.

Their role is to help NSAI increase Ireland's pool of knowledge relating to hydrogen standardisation, drawing on the widest possible panel of experts including policymakers, researchers, and industry professionals.

Since the appointment of the Hydrogen Standardisation Expert, NSAI has recruited approximately 55 gas related committee members. With the focused work of the Hydrogen Standardisation Expert and growing expertise on the relevant national Technical Committees, NSAI has been able to closely monitor and participate on European and International hydrogen related committees and working groups.

An example of the extensive work that is currently being done at European level and that is being closely reviewed by NSAI's Gas Technical Standards Committees, is the revision and development of standards on gas quality in existing gas systems to incorporate hydrogen and hydrogen quality in rededicated gas systems. This work is in response to the EU hydrogen and decarbonised gas package and demonstrates the increased cooperation between the European Commission and the European Standardisation Organisations, CEN and CENELEC, to ensure an aligned and balanced approach in the delivery of the European Green Deal.

The figure below represents Technical Committees involved with hydrogen topics, highlighting the complexity and the large number of actors involved in the hydrogen standardisation process.

As Ireland takes the opportunity to become a net exporter of green hydrogen, Ireland can also take this opportunity to be a leader in setting best practice through standards, in such areas as hydrogen production and storage.

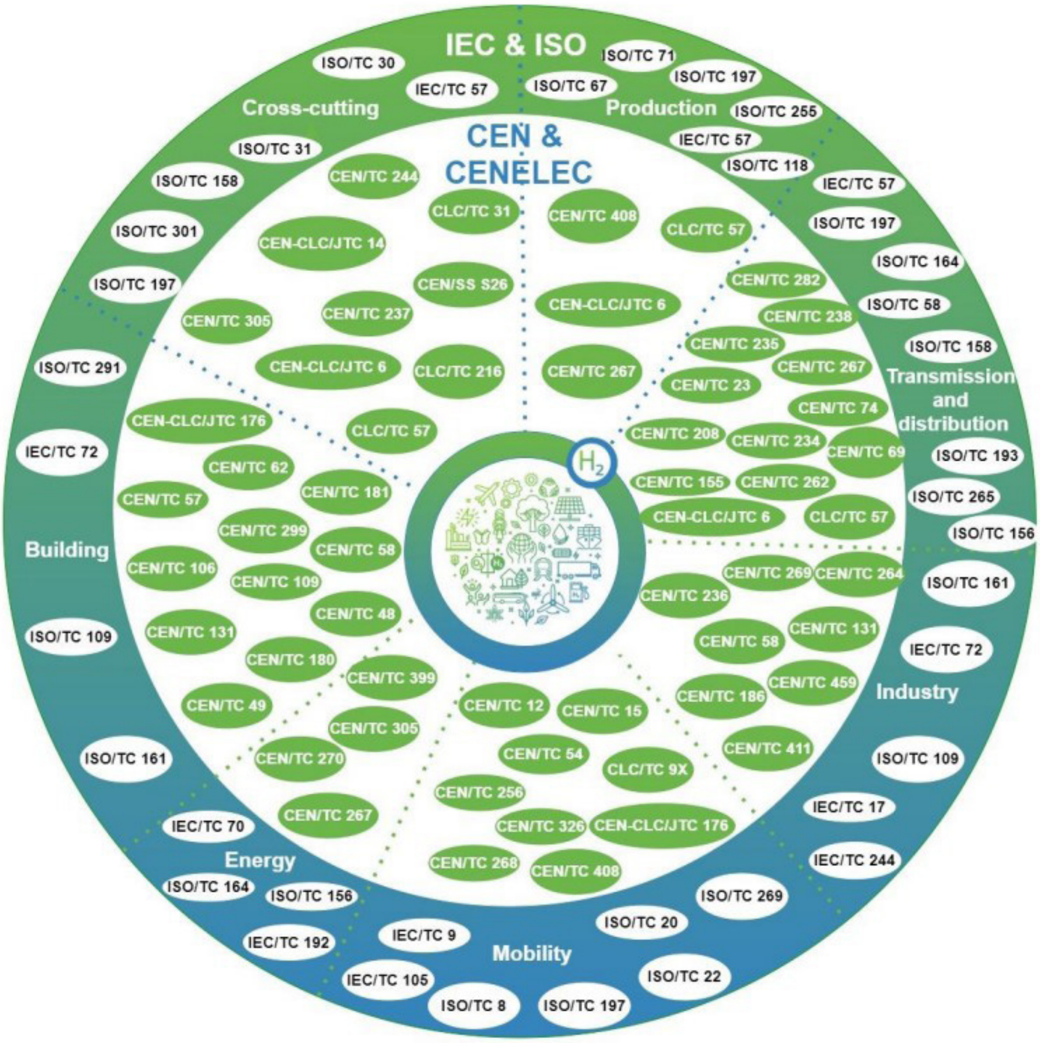


Figure 11: European and international standardisation landscape for hydrogen topics[68]

Hydrogen Leakage and Emissions

There have been some concerns raised regarding the potential for hydrogen leakage from infrastructure acting as an indirect greenhouse gas, as it interacts with other gases in the earth's atmosphere. There have also been some concerns raised about the potential for high nitrous oxide (NOx) emissions associated with certain end uses of hydrogen such as combustion in high temperatures for power generation and high process heating. These concerns are already being studied at a European level, with the potential development of standards to mitigate their potential risks. Ireland will monitor and adopt suitable European and international standards as they emerge in this space to keep these risks as low as practical. Further research and studies at a national level may be considered if a need to assess Ireland specific circumstances is identified.

[68] 20230301_ech2a_roadmaphydrogenstandardisation.pdf (cencenelec.eu)

Hydrogen Licensing and Permitting

Undertaking a full review to identify any gaps in the licensing and permitting regimes that affect the hydrogen value chain will be an important activity to undertake during the early stages of implementation of this strategy. For example, it has already been identified that the current prospecting permitting regime would pose a barrier to hydrogen storage projects. It is particularly important to remove these barriers in a timely manner so as to not hinder the progress of early hydrogen projects.

Public Awareness and Support

Given its limited use in Ireland today, efforts will be required to create a better understanding across the public in respect to hydrogen. This will be key to future public acceptance of hydrogen. A key part of this will be through the development of initial demonstration applications, such as the Dublin bus trials currently ongoing. Further demonstrations of the technology are welcome. In addition to this, further efforts should be made to create greater public awareness.

Actions

1. Establish a working group with the relevant regulators, government, and industry representatives to develop a safety roadmap to delivering the necessary safety frameworks and regulatory regimes across the entire hydrogen value chain
2. Adopt the hydrogen and decarbonised gases market package into legislation once approved by the EU institutions
3. Undertake a review across the entire hydrogen value chain to identify any other gaps within our spatial planning, environmental permitting, and licensing regimes

6 Research, Cooperation and Scaling Up

Key Messages

- Renewable hydrogen is still a nascent technology. Global research and innovation over the coming years will be essential to future competitiveness and scale up.
- Climate research is a strategic priority of Ireland's research and innovation strategy, as set out in Impact 2030: Ireland's Research and Innovation Strategy
- Ireland has a proven track record in supporting research and innovation, as well as delivering results.
- Targeted, short-term research needs have been identified throughout the National Hydrogen Strategy which will be essential to ensuring future informed policy making in the space.
- The European Union has invested heavily in supporting hydrogen related research and development initiatives. Leveraging these resources and applying them to Ireland will be important.
- Further work to build strategic international partnerships in the fields of renewable hydrogen development will be an important enabler.
- Further work is needed to better determine the skills required, short falls and the opportunities for employment in Ireland in respect to renewable hydrogen.

The development of a hydrogen industry for the purposes of enhancing sector integration and enabling the transition to a decarbonised economy is still at a relatively early stage, both in Ireland and internationally. Significant work is required across the entire value chain to enable the technological developments, the scale up of supply chains, and development of the hydrogen market that will allow renewable hydrogen to become a cost-effective energy carrier over time.

Strategic efforts during the early years will be essential to achieving this. Progressing focused research to inform future policy, general support for research and demonstration across the value chain, close cooperation and international partnership, leveraging work already ongoing in other jurisdictions and continued support for our further and higher education institutions, state research bodies, and research and innovation funding agencies that can help to ensure the correct skillsets will be available in the future to deliver on the hydrogen opportunity for Ireland will all be important enablers.

Continued Support for Research and Innovation

Ireland has strategically built a strong research and innovation culture in recent years. Impact 2030: Ireland's Research and Innovation Strategy[69], Ireland's research and innovation strategy, seeks to advance strategic research and innovation development and to maximise the impact on our economy, society, and environment. Within this, there is a focus on key societal challenges including climate, environment, and sustainability. The national research and innovation system consists primarily of higher education institutions (HEIs), research-active Government Departments and Agencies and research-active enterprises and civil society organisations.

69 gov.ie - Impact 2030: Ireland's Research and Innovation Strategy (www.gov.ie)

Within higher education, many institutions are already involved in climate-related research and innovation, including hosting Enterprise Ireland (EI)/IDA Technology Centres, EI Technology Gateways, and Science Foundation Ireland (SFI) Research Centres. These centres and funded research programmes allow Irish HEIs (including the new Technological Universities) to collaborate and work with small and medium-sized enterprises (SMEs) and multinationals, to develop the talent and skills needed for the jobs of the future, and to provide innovative technologies, new processes, and insights to address key challenges. The Government provides significant funding to Ireland's research-performing organisations to carry out climate-related research in the sciences and humanities and to carry out policy-relevant research. These organisations are also active in sourcing climate-related research funding from various European funding programmes. It will be important to engage with this sector over the coming years to ensure sufficient focus is given to supporting the needs of a developing hydrogen sector in Ireland, and to identify what additional mechanisms, if any, are required to support this.

Case Study

The HyLight Project

HyLIGHT is an all island 3-year project funded by Science Foundation Ireland (SFI) and a 25-strong industry consortium led by Dublin City University, in partnership with University of Galway, and University College Cork through MaREI. The overall aim of HyLIGHT is to provide viable Roadmaps towards an all island fully decarbonised, secure energy system in 2050.

One of the objectives within this analysis is to scrutinise the potential role of hydrogen in the energy transition along a path to 2050. Work packages go beyond the basics and focus on state-of-the-art projections of economic and geopolitical factors, global industry intelligence, scenario analysis and multi criterion analysis, affecting the production, supply, and demand of hydrogen in electricity, industry, eFuels and transport sectors in Ireland. HyLIGHT researchers are working with world class geologists and leading global companies to understand real opportunities for large scale hydrogen storage potential on the island north and south. HyLIGHT recognises that decarbonisation must happen within the social licence of the public and therefore safety, socio economic factors, as well as life cycle assessment of projects are assessed to explore how the people of Ireland can gain value.

HyLIGHT is developing knowledge and present peer reviewed outputs, data, tools, objective results and scenarios that can help inform regulation and policy to understand where hydrogen fits in Ireland's decarbonisation strategy.

Figure 12: Hylight Project Consortium Partners

Targeted Research to Inform Future Policy in this space

In 2022, the Department of the Environment, Climate and Communications funded a range of research programmes totalling over €40 million70.The majority of this funding supports research funding programmes offered by the Environmental Protection Agency (EPA) through its EPA Research Framework, and the Sustainable Energy Authority of Ireland (SEAI) who funds a range of RD&D activities relating to the production, supply and use of energy. EPA and SEAI also carry out in-house research and evidence production. Geological Survey Ireland (GSI) also run a research programme to provide data on past climates and Ireland's geological properties, and offer competitive research funding. The Department also procures support directly from the national research and innovation system through research and consultancy frameworks.

Through the development of this strategy, a number of areas where further research is needed to better inform policy making were identified. Work over the coming years to commission the necessary research in these areas to better inform future policy making during the implementation of this strategy is needed.

[70] gov.ie – Research and Development Budget: 2021 to 2022 (www.gov.ie)

Technology Demonstrations

Currently there is little to no hydrogen production in Ireland. End-users require greater certainty in respect to the availability and likely costs of hydrogen. The development of a small number of demonstrator projects can help with this in the early years. These projects can help to create more transparency and a better understanding of the commercial business models. They also can act as an enabler to identifying and helping to alleviate any potential regulatory, consenting and supply chain barriers that may exist for future projects. Demonstration projects also offer a chance for end-users and the public to physically see and experience the hydrogen technology. This experience is key to public buy in and providing the necessary reassurances to prospective end users.

Ireland will enable the development of a small number of hydrogen demonstration projects during the 2020s, and in parallel work to deliver the requisite safety and regulatory regimes. Further assessment on the types of projects that would be suitable and how best to enable their deployment will be progressed during the early stages of the implementation of this strategy.

Research and Hydrogen Development Support through International and EU Channels

At European Union (EU) level, there are several programmes providing funding opportunities for research and innovation. Horizon Europe is the EU's key funding programme for research and innovation. It tackles climate change, helps to achieve the United Nations' Sustainable Development Goals and boosts the EU's competitiveness and growth. It supports research and innovation projects primarily through competitive grant calls, and includes activities pursued by the Joint Research Centre which supports policymakers with independent scientific evidence and technical support. Horizon Europe has earmarked 35% of its total budget towards climate objectives. Funding for climate-related research and action is also provided by the EU Innovation Fund, the LIFE programme, the European Regional Development Fund (ERDF) as part of European Structural and Investment Funds, and COST (European Cooperation in Science and Technology), that funds bottom-up, open research and innovation networks. Specific European hydrogen related initiatives are outlined below in more detail. Continued engagement and support for these initiatives will be an important part of ensuring Ireland remains aligned with other EU member states and at the forefront of hydrogen development internationally.

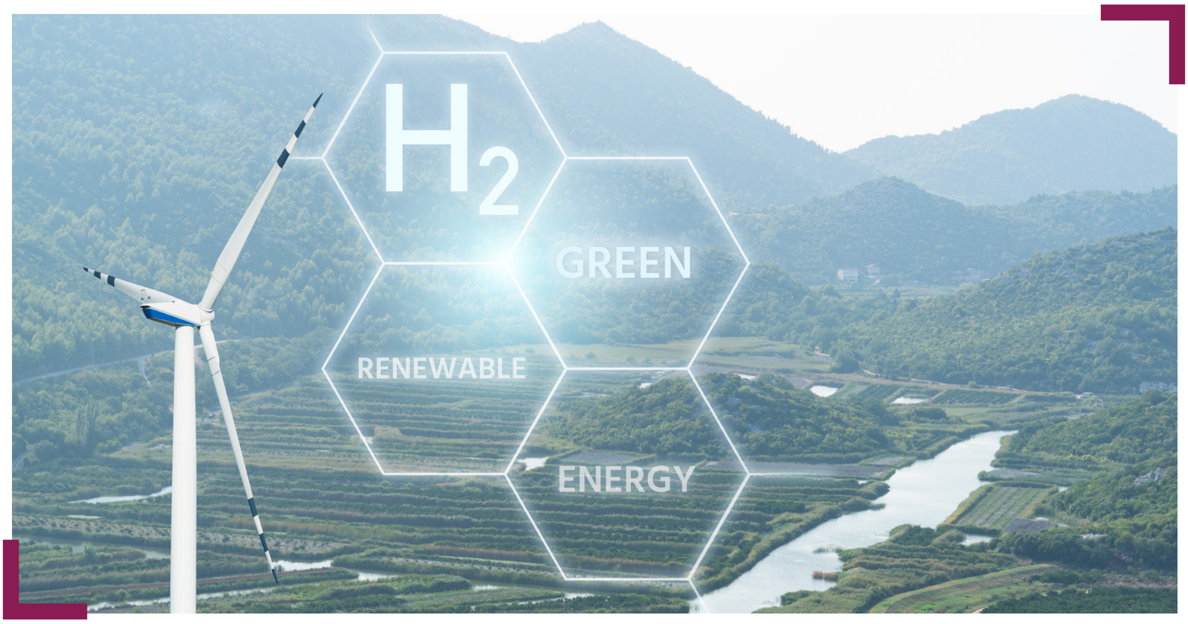


Table 12: European Hydrogen Related Initiatives

Initiative	Description
European Clean Hydrogen Partnership	The Clean Hydrogen Partnership is a joint public-private partnership with Hydrogen Europe, supported by the Commission through Horizon Europe. Its aim is to strengthen and integrate EU scientific capacity, to accelerate the development and improvement of advanced clean hydrogen applications. €1 bn has been assigned during up to 2027 to commission research and innovation into clean hydrogen related technologies development.
EU Clean Hydrogen Alliance	The EU Clean Hydrogen Alliance brings together industry, national and local authorities, civil society and other stakeholders with the aim of promoting investments and stimulating clean hydrogen production and use. It launched six thematic roundtables in key areas of hydrogen production, transportation and use and published a hydrogen project pipeline in November 2021 with 840 projects. It also hosts the 'Electrolyser Partnership' to bring together electrolyser manufacturers and suppliers of components and materials to achieve a combined annual electrolyser manufacturing capacity of 17.5 GW by 2025 in Europe.
Projects of Common/ Mutual Interest	The Trans-European Networks for Energy (TEN-E) regulation sets out the criteria for projects to be considered for Projects of Common / Mutual Interest (PCI/PMI) status in Europe, opening faster permitting procedures and access to funding for grants and capital works under the Connecting Europe Facility. In June 2022, it was updated to better reflect the decarbonisation needs of Europe, introducing new categories hydrogen pipelines, hydrogen storage facilities, hydrogen terminals, and electrolysers, amongst others. The first tranche of projects under the new process are now being assessed and will be published in Q3 2023.
European Hydrogen Bank	The main objective of the facility is to unlock private investments in hydrogen value chains, both domestically and in third countries, by connecting renewable energy supply to EU demand and addressing the initial investment challenges. It will establish an initial market for renewable hydrogen, offering new growth opportunities and jobs. In autumn 2023, a pilot auction will be launched under the EU Innovation Fund, supporting the production of renewable hydrogen for European consumers
Important Projects of Common European Interest (IPCEIs)	IPCEIs allow Member States greater flexibility to grant State aid to specific companies or projects, as long as it is in an area which has potential to advance broader EU objectives and community and addresses a strategic or market failure that no other tool is able to address. Unless a smaller number is justified by the nature of the project, the project must ordinarily involve at least four Member States and receive a mixture of private / public funding. In 2022, two hydrogen IPCEIs were approved by the European Commission. "Hy2Tech" notified in July 2022 including 35 companies with 41 projects across 15 Member States providing €5.4 billion of public funding and €8.8 billion of private investment, and "Hy2Use" notified in September 2022 including 29 companies with 35 projects across 13 Member States providing €5.2 bn of public funding and €7 bn of private funding. Two further Hydrogen IPCEI - Hy2SupplyInfra and Hy2Move – are also in development and are expected to be completed in 2023.

continued

Initiative *(continued)*	Description *(continued)*
European Hydrogen Backbone Initiative	The European Hydrogen Backbone (EHB) initiative consists of a group of thirty-two energy infrastructure operators, which aims to accelerate Europe's decarbonisation journey by defining the critical role of hydrogen infrastructure – based on existing and new pipelines – in enabling the development of a competitive, liquid, pan-European renewable and low-carbon hydrogen market.
Hydrogen Energy Network (HyENet)	Bi-annual meeting of representatives from the energy ministries in EU countries that aims to help national energy authorities build on the opportunities offered by hydrogen as an energy carrier. It acts as an informal platform to share information on good practices, experience, and the latest developments in hydrogen.
Net Zero Industrial Act (NZAI)	The proposal is designed to support the scaling up of the EU's net-zero manufacturing capacities and products helping to meet Europe's climate neutrality goals, create green jobs and maintain the EU's competitiveness. It sets a benchmark for the manufacturing capacity of strategic net-zero technologies to meet at least 40% of the EU's annual deployment needs by 2030, including renewable hydrogen. The proposed NZIA aims to streamline administrative and permitting requirements for technology developers in Europe, whilst facilitating greater access to markets in public procurement and schemes to support greater consumer demand.
North Seas Energy Cooperation	The North Seas Energy Cooperation (NSEC) supports and facilitates the development of the offshore grid development and the large renewable energy potential in the region, including the potential to produce renewable hydrogen. Its members include Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, Sweden, and the European Commission.

Bilateral partnerships and cooperation

In addition to active engagement in hydrogen areas of development within the EU, it will also be important to form bilateral partnership in the field of hydrogen cooperation with certain countries with whom Ireland shares particular strategic synergies.

On 31st May 2023, Ireland signed a Declaration of Intent (DoI) with Germany to initiate their cooperation on research and development in the field of production, storage, transport, and use of renewable hydrogen including its derivates. Germany launched its hydrogen strategy in June 2020 outlining a need for 90-110 TWh of hydrogen by 2030 to meet its domestic demand whilst aiming to produce around 14 TWh of renewable hydrogen production. Ireland with its vast potential renewable resources may be well placed to kick-start an export market for renewable hydrogen to support this. The DoI aims to better explore the establishment of a joint pilot project on potential renewable hydrogen cross-border value chains between Ireland and Germany.

Today, Ireland imports the majority of its natural gas supplies from Britain and there is a successful Single Electricity Market for the island of Ireland. It is imperative that Ireland engages closely with its partners in the United Kingdom Government and Northern Ireland Executive in respect to opportunities in the field of renewable and low carbon hydrogen. In recognition of this, work is currently underway to develop a Memorandum of Understanding (MoU) between the Government and the United Kingdom Government covering a wide variety of energy related topics including the development of hydrogen in our energy systems.

Shared Island context

Both Ireland and Northern Ireland now have common carbon emission reduction goals and statutory requirements. The cross-border connections in energy and transport, and in broader economic terms, provide important opportunities for strategic cooperation on green energy transition on a shared island basis. The revised National Development Plan (2021-2030) includes a priority on exploring potential cross-border and all-island approaches on renewable energy, including on the potential of hydrogen.

Close cooperation will continue with Northern Ireland counterparts and through the North South Ministerial Council, where hydrogen has been identified as a potential area for future cooperation under the areas of environment and transport, with possible funding opportunities through the Government's Shared Island Fund. Already, as part of the Shared Island initiative, both Administrations on the island are supporting a feasibility study to assess the potential to establish hydrogen refuelling stations along the main road network between Dublin and Belfast, which is the most intensively used transport route by heavy duty vehicles on the island.

Further work is needed to build on and formalise these partnerships in the coming years, as well as look to develop further partnerships to ensure Ireland is well placed to deliver on our hydrogen ambitions.

Developing skills for the hydrogen economy

Ireland will need to facilitate the skills development and training necessary for jobs in the hydrogen sector. In the short term, many of the potential new offshore wind and hydrogen economy jobs will be in the construction sector. Other key skills needed for the offshore wind and hydrogen economy include technical roles such as civil, electrical, chemical, and geotechnical engineering, alongside support functions in areas like logistics and supply chain management, sustainable finance, and health and safety. The responsiveness of the education and training system to facilitate the development of the workforce with the skills and capabilities to meet this demand, will be an important component to delivering on the opportunities of the hydrogen economy. Further work is needed to better understand the skills required to build, maintain, and operate hydrogen related infrastructure, and how these skills can be best developed to suit the objectives of Ireland's hydrogen economy.

More generally, Ireland has an advanced system of skills provision, across Further and Higher Education, lifelong learning and human capital development, which is agile and responsive to changes in the world of work, in order to address evolving skills needs. This includes the skills requirements for the green transition in general, and skills requirements for the hydrogen economy in particular. Engagement and collaboration between relevant Government Departments and agencies, the education and training system, and enterprise is essential to understand emerging skills requirements, including those related to hydrogen technologies. This engagement and collaboration is fostered through Ireland's skills architecture, which includes the National Skills Council, nine regional skills fora, and the broader skills ecosystem encompassing entities including the Skills and Labour Market Research Unit (SLMRU, hosted in SOLAS), the Expert Group on Future Skills Needs (EGFSN) and the National Training Fund Advisory Group (NTFAG). While the Department of Further and Higher Education, Research, Innovation and Science (DFHERIS) has responsibility for skills policy, this broader skills ecosystem informs and drives responsive, flexible forecasting, planning, and provision. In the area of skills for the green transition, reports including the EGFSN's Skills for Zero Carbon: The Demand for Renewable Energy, Residential Retrofit and Electric Vehicle Deployment Skills to 2030 have set out skills requirements for the development of renewable energy, including on and offshore wind, between now and 2030. We must also work to understand the skills required to build, maintain, and operate hydrogen related infrastructure, and how these skills can be best developed to suit the objectives of Ireland's hydrogen economy.

The Department of Enterprise, Trade and Employment (DETE) will publish a National Industrial Strategy for Offshore Wind in 2024 setting out how Ireland can maximise the economic opportunity arising from the production of Offshore Wind Energy including the skills required to support this. This Strategy is expected to include measures to develop both indigenous and export demand for energy derived from Offshore Wind which may include the large-scale production of hydrogen and its derivatives. The Industrial Strategy will be developed in close consultation with the Department of Environment, Climate, and Communications, the Offshore Wind Delivery Taskforce, as well as other key Departments, Agencies, and industry.

Actions

1. Engage with Ireland's research sector to ensure sufficient focus is given to renewable hydrogen development and work to commission relevant research to help close the knowledge gaps identified throughout the National Hydrogen Strategy
2. Continue to engage in EU hydrogen related initiatives and develop cooperation in the fields of renewable hydrogen development with neighbouring jurisdictions and international partners
3. Through the expert advisory group on skills established under the Offshore Wind Delivery Task force, continue to assess, and support the future skill needs of the offshore wind and renewable hydrogen sectors

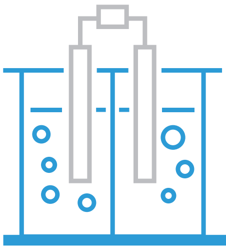
7 Delivery and Implementation

Ireland's Strategic Hydrogen Development Timeline Roadmap

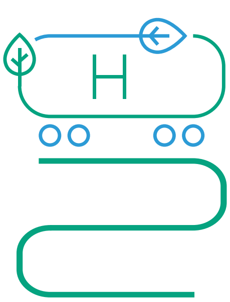
Our strategic hydrogen development timeline roadmap below sets out our vision for how we expect the hydrogen economy to develop and scale up over the coming decades, across the entire value chain. It can act as a simple guide to show when different components of the hydrogen sector are anticipated to be needed by as the sector ramps up during the transition to net zero.

Along with the list of actions published as part of this National Hydrogen Strategy, it will help to provide clarity on the sequencing of future actions needed and guide our work over the coming months and years.

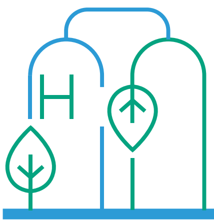
Table 14: Ireland's strategic hydrogen development timeline roadmap



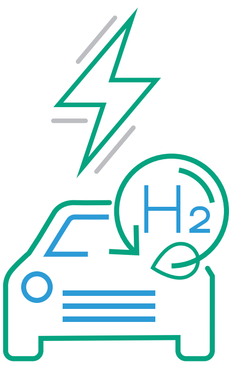
Production	2023-28	2028-33	2033-38	2038-50
Renewable hydrogen produced from curtailed grid electricity or onshore renewables where available	Large scale deployment envisioned	Large scale deployment envisioned	Large scale deployment envisioned	Large scale deployment envisioned
Hydrogen blends across the interconnectors	Small number of niche applications	Small number of niche applications	Small number of niche applications	Unlikely to exist
Renewable hydrogen from Offshore Wind	Unlikely to exist	Small number of niche applications	Large scale deployment envisioned	Large scale deployment envisioned



Transportation	2023-28	2028-33	2033-38	2038-50
Trucked (non-pipeline) or onsite use	Large scale deployment envisioned	Large scale deployment envisioned	Small number of niche applications	Small number of niche applications
Network blending	Small number of niche applications	Small number of niche applications	Unlikely to exist	Unlikely to exist
Local networks/clusters	Unlikely to exist	Large scale deployment envisioned	Large scale deployment envisioned	Small number of niche applications
National hydrogen network	Unlikely to exist	Unlikely to exist	Small number of niche applications	Large scale deployment envisioned
Import/Export Routes established	Unlikely to exist	Unlikely to exist	Small number of niche applications	Large scale deployment envisioned



Storage	2023-28	2028-33	2033-38	2038-50
Network blending	Small number of niche applications	Small number of niche applications	Unlikely to exist	Unlikely to exist
Small scale storage applications	Large scale deployment envisioned	Large scale deployment envisioned	Small number of niche applications	Small number of niche applications
Large scale storage solutions of geological scale	Unlikely to exist	Small number of niche applications	Large scale deployment envisioned	Large scale deployment envisioned



End Uses	2023-28	2028-33	2033-38	2038-50
Existing Large Energy Users on gas network using GOs	Small number of niche applications	Small number of niche applications	Unlikely to exist	Unlikely to exist
Heavy Land Transport	Small number of niche applications	Large scale deployment envisioned	Large scale deployment envisioned	Small number of niche applications
Power Generation	Unlikely to exist	Small number of niche applications	Large scale deployment envisioned	Large scale deployment envisioned
Industrial Heating	Unlikely to exist	Small number of niche applications	Large scale deployment envisioned	Large scale deployment envisioned
Aviation and Shipping	Unlikely to exist	Unlikely to exist	Small number of niche applications	Large scale deployment envisioned
Exports	Unlikely to exist	Unlikely to exist	Small number of niche applications	Large scale deployment envisioned

Unlikely to exist | Small number of niche applications | Large scale deployment envisioned

Table 15: List of actions to be delivered through the National Hydrogen Strategy

#	Action	Timeline
1	Develop and publish data sets showing the likely locations, volumes, and load profile of surplus renewables on our electricity grid out to 2030	2023-24
2	Establish an early hydrogen innovation fund to provide co-funding supports for demonstration projects across the hydrogen value chain	2023-27
3	Adopt EU standards for renewable and low carbon hydrogen and develop a national certification scheme to provide clarity to end users as to the origin and sustainability of their hydrogen	2023-25
4	Develop the commercial business models to support the scale up and development of renewable hydrogen, targeting surplus renewable grid electricity pre-2030 and an initial 2 GW of offshore wind from 2030	2023-30
5	Develop a roadmap to bring net zero dispatchable power solutions to market by 2030, to support the delivery of a near net zero power system by 2035	2024-26
6	Undertake further work to assess the role that integrated energy parks could play in our future energy system, including their potential benefits and the possible barriers (market, legal or other) that may exist	2023-25
7	Publish the draft National Policy Framework on Alternative Fuels Infrastructure, and support the roll-out of hydrogen powered heavy duty vehicles and refuelling infrastructure in line with EU requirements set out in the recast Renewable Energy Directive and Alternative Fuel Infrastructure Regulation	2024-30
8	Through the development of the National Industrial Strategy for Offshore Wind, assess the feasible potential for end uses such as eFuels, decarbonised manufacturing and export of Hydrogen and its derivatives.	2024-26
9	Undertake further work to determine the quantities and profile of zero carbon long duration energy storage needed out to 2050, and develop a roadmap as to how it can be delivered	2024-26
10	Undertake a review of the existing licensing and regulatory regimes relevant to the geological storage of hydrogen, and progress the necessary legislative changes and development of regulatory regimes to facilitate future prospecting and development of underground hydrogen storage solutions	2024-28
11	Continue work to prove the technical capabilities of the gas network to transport hydrogen through the network and closely work with the network operators in neighbouring jurisdictions in respect to interoperability between the networks	2023-28
12	Develop a plan for transitioning the gas network to hydrogen overtime, taking due consideration of: a. plans to develop a biomethane sector in Ireland, b. the prioritisation of end uses set out in the National Hydrogen Strategy and their likely locations where known, c. the need to maintain energy security through the transition, d. how existing end users can transition from natural gas to hydrogen, or to alternative energy solutions such as electric heating, e. the potential use of hydrogen blends during a transition phase, the costs associated and how the transition from blending can occur The plan should look to identify where the network can be repurposed, or where new pipelines may be required and provide detailed costings and a programme of works	2023-26

continued

#	Action *(continued)*	Timeline
13	Progress work to identify and support the development of strategic hydrogen clusters	2024-26
14	Commence a review of current approaches to energy systems planning and make recommendations to support a more integrated long-term approach to planning across the network operators including electricity, natural gas, hydrogen, and water	2024-26
15	Establish a working group with the relevant regulators, government, and industry representatives to develop a safety roadmap to delivering the necessary safety frameworks and regulatory regimes across the entire hydrogen value chain	2024-26
16	Adopt the hydrogen and decarbonised gases market package into legislation once approved by the EU institutions	2024-27
17	Undertake a review across the entire hydrogen value chain to identify any other gaps within our spatial planning, environmental permitting, and licensing regimes	2024-26
18	Engage with Ireland's research sector to ensure sufficient focus is given to renewable hydrogen development and work to commission relevant research to help close the knowledge gaps identified throughout the National Hydrogen Strategy	2024 – ongoing
19	Continue to engage in EU hydrogen related initiatives and develop cooperation in the fields of renewable hydrogen development with neighbouring jurisdictions and international partners	2024- ongoing
20	Through the expert advisory group on skills established under the Offshore Wind Delivery Task force, continue to assess, and support the future skill needs of the offshore wind and renewable hydrogen sectors	2023- ongoing
21	Review and update the Terms of Reference of the Interdepartmental Hydrogen Working Group to recognise its role in terms of oversight and implementation of the National Hydrogen Strategy	2023-24

Governance and Implementation

Whilst this hydrogen strategy sets out the opportunities, priorities, and enablers to development of hydrogen in Ireland, continued effort is needed to implement the key actions needed to support the development of an indigenous renewable hydrogen industry. It is envisioned that the actions set out in this hydrogen strategy will be included in future versions of the Climate Action Plan to ensure their delivery.

Hydrogen is developing at a rapid pace internationally and as a result, it is also important to continually monitor and benchmark this strategies ambitions, in line with developments internationally. Whilst the strategy has been written in a manner which ensures early focus on delivery of the no regrets activities that are essential, it will also be important to ensure that future emerging international best practices are taken into consideration. To that extent, the Interdepartmental Hydrogen Working Group can play an important role in ensuring these areas are identified and reflected in future thinking. Whilst no specific periodic timelines are proposed to revise this strategy, as further details emerge from international developments and targeted research commissioned, it is likely that this strategy will be updated accordingly to reflect this.

Actions

1. Review and update the Terms of Reference of the Interdepartmental Hydrogen Working Group to recognise its role in terms of oversight and implementation of the National Hydrogen Strategy

8 Endnotes

Glossary of Acronyms

Acronym	Full description
ADR	Agreement concerning the international carriage of Dangerous goods by Road
AFIR	Alternative Fuels Infrastructure Regulation
ALARP	As Low As Reasonably Practicable
BECCS	Bioenergy with Carbon Capture and Storage
BEV	Battery Electric Vehicle
°C	Degrees Celsius
CAP	Climate Action Plan
CCS	Carbon Capture and Storage
CH4	Methane
CO2	Carbon Dioxide
COST	European Cooperation in Science and Technology
COMAH	Control of major accident hazards involving dangerous substances
CRU	Commission for Regulation of Utilities
CxHx	Hydrocarbons
D/Finance	Department of Finance
D/Transport	Department of Transport
DAFM	Department of Agriculture, Food and the Marine
DART	Dublin Area Rapid Transit
DECC	Department of the Environment, Climate and Communications
DETE	Department of Enterprise, Trade, and Employment
DFHERIS	Department of Further and Higher Education, Research, Innovation and Science
DHLG	Department of Housing, Local Government and Heritage
DoI	Declaration of Intent
DPER	Department of Public Expenditure, NDP Delivery and Reform
DTAGSM	Department of Tourism, Culture, Arts, Gaeltacht, Sport and Media
ECH2A	European Clean Hydrogen Alliance
EGFSN	Expert Group on Future Skills Needs
EHB	European Hydrogen Backbone initiative
EI	Enterprise Ireland
EPA	Environmental Protection Agency
ERDF	European Regional Development Fund
EU	European Union
FCEV	Fuel Cell Electric Vehicle
GoO	Guarantee of Origin
GNI	Gas Networks Ireland
GSI	Geological Survey Ireland
GW	Gigawatt

GWh	Gigawatt-Hour
H2	Hydrogen
H2O	Water
HDV	Heavy Duty Vehicle
HEI	Higher Education Institutes
HGV	Heavy Goods Vehicle
HSA	Health and Safety Authority
HyENet	Hydrogen Energy Network
IDA Ireland	Industrial Development Agency (Ireland)
IEA	International Energy Agency
IMDO	Irish Maritime Development Office
IPCEI	Important Project of Common European Interest
IRENA	International Renewable Energy Agency
ISIF	Ireland Strategic Investment Fund
ISO	International Organisation for Standardisation
Kg	Kilogram
KPI	Key Performance Indicator
Kt	Kiloton
kW	Kilowatt
kWh	Kilowatt-Hour
LA	Local Authority
LCOH	Levelised Cost Of Hydrogen
LOHC	Liquid Organic Hydrogen Carriers
MaREI	Research Centre for Energy, Climate, and Marine Research and Innovation
MoU	Memorandum of Understanding
MtCO2eq.	Million Tonnes of Carbon Dioxide Equivalent
MW	Megawatt
NSEC	North Seas Energy Cooperation
NOx	Nitrogen Oxides
NSAI	National Standards Authority of Ireland
NTA	National Transport Authority
NZIA	Net-Zero Industry Act
ORE	Offshore Renewable Energy
OWE	Offshore Wind Energy
PCI	Project of Common Interest
PMI	Project of Mutual Interest
R&D	Research and Development

RD&D	Research, Development and Demonstration
RED	Renewable Energy Directive
RFNBOs	Renewable Fuels of Non-Biological Origin
SAFs	Sustainable Aviation Fuels
SEAI	Sustainable Energy Authority of Ireland
SFI	Science Foundation Ireland
SLMRU	Skills and Labour Market Research Unit
SOLAS	Further Education and Skills Service
SME	Small-to-Medium Enterprise
TEN-E	Trans-European Energy Networks
TW	Terawatt
TWh	Terawatt-Hour

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