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Hydrogen in Ireland Discussion Paper

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1. Introduction

This discussion paper has been prepared by the Secretariat to the Climate Change Advisory Council in order to inform a thematic discussion on the potential role of hydrogen in decarbonisation and achievement of the National Climate Objective in Ireland as set out in the Climate Action and Low Carbon Development (Amendment) Act 2021.

Green hydrogen can be produced from renewable electricity through electrolysis of water with production of close to zero greenhouse gas emissions though the full production process. This differs from other forms of hydrogen production, which for example use natural gas or methane and emit carbon dioxide as a by-product[1].

Green hydrogen produced from renewable electricity[2] is the focus of this discussion paper, based on stated policy within the Climate Action Plan 2023 and recent consultation on 'Developing a Hydrogen Strategy for Ireland' to focus on development of green hydrogen.

1.1. Current Targets, Production and Use of Hydrogen in Ireland

A hydrogen strategy for Ireland is currently in development and a consultation on 'Developing a Hydrogen Strategy for Ireland' was recently conducted by DECC, closing on the 2nd of September 2022.

The 2021 National Climate Action Plan (NCAP 2021) set out a target of identifying a route to deliver 1-3 TWh[3] of zero emissions gas (including green hydrogen, but also biomethane) by

[1] Hydrogen is commonly differentiated based on the energy sources and technologies used for production and their carbon intensity. Green hydrogen is produced from renewables through electrolysis of water, while blue hydrogen is produced from natural gas using a process called steam reforming but with associated output of carbon dioxide captured using CCS. Grey hydrogen is currently the most common form of hydrogen production using steam methane reformation but without capturing the greenhouse gases made in the process.

[2] The EU Hydrogen Strategy also notes that renewable hydrogen may also be produced through the reforming of biogas (instead of natural gas) or biochemical conversion of biomass, if in compliance with sustainability requirements, however this is not considered in detail in this paper based on SEAI's Heat Study findings regarding the limitation of hydrogen production via this method in Ireland.

[3] Different units of energy are referred to in this discussion paper. kW is a unit of power or the rate at which energy is generated or used. Installed generation is generally referred to in terms of the rate at which it can generate energy, or its power, e.g., X kW or MW of wind generation installed in X location. kWh is a unit of energy over a specific period of time and is related to power through the following equation: energy = power*time. For example, the total installed wind capacity was 4,330 MW in 2021, but the total wind generation was 9,530,000MWh. A MW is equal to 1000kW, a GW is 1000MW and a TW is 1000GW. Electricity generated or used (for example on your electricity bill) is generally measured and recorded as kWh/MWh/GWh/TWh. Electricity generated from renewable electricity is also dependent on its capacity factor, which is the ratio of average electricity produced to the theoretical maximum possible if the installed capacity was generating at a maximum for a full year. The wind capacity factor on average between 2012-2021 was 28%. The amount of hydrogen that can be produced from wind also depends on the efficiency of a particular electrolyser and on the efficiency of different storage mechanisms. The efficiency of electrolysers varies from 60-80% but not all are at the same readiness level for widescale deployment.

2030 and the introduction of incentives for electrolyser production and grid connection of green hydrogen. As part of the agreement of sectoral emissions ceilings in July 2022[4], the target for offshore wind installation was increased from 5,000 MW to 7000 MW, with the additional 2,000 MW earmarked for green hydrogen production, which has also been included in the 2023 National Climate Action Plan (NCAP 2023). This also includes a measure for green hydrogen production from surplus renewable electricity by 2030 in the electricity sector and the development of policies to ensure zero carbon gases such as hydrogen are utilised in the electricity sector to provide zero carbon dispatchable electricity. In the Industry Sector of within NCAP 2023, an action to be progressed in 2023 is the development of a policy/regulatory roadmap for green hydrogen use.

Specific actions relating to hydrogen set out in the NCAP 2021 Annex of Actions (with the Annex of Actions for NCAP 2023 due for publication) include testing the technical feasibility of safely injecting green hydrogen blends in the gas grid, assessing the potential for system integration between the electricity and gas networks, including the production, storage and use of green hydrogen, developing a policy/regulatory roadmap for green hydrogen use in the gas grid and progressing research and pilot studies regarding the use of hydrogen in the transport sector.

There are currently no hydrogen networks in Ireland with some limited use of hydrogen by the Whitegate oil refinery which has utilised hydrogen as part of the refining process since 1959 and some industry sectors, contrasting to a number of EU countries where significant hydrogen demand has developed primarily in industrial applications. . Refineries use hydrogen to remove impurities and to upgrade heavy oil fractions into lighter products (IEA, 2022). Part of the facility’s existing hydrogen demand is for the production of hydrogenated vegetable oil (HVO) and Fatty Acid Methyl Este (FAME), biofuels which can replace or be blended with fossil diesel (Wind Energy Ireland, 2022).

There are a number of hydrogen supply projects underway in Ireland and Northern Ireland, for example:

- Indaver has been granted planning permission for a 10 MW hydrogen generation unit, to produce hydrogen using its Waste-to-Energy plant during times of excess electricity generation[5].

[4] The press release in relation to sectoral emissions ceilings is available here; https://www.gov.ie/en/press-release/dab6d-government-announces-sectoral-emissions-ceilings-setting-ireland-on-a-pathway-to-turn-the-tide-on-climate-change/

[5] https://www.indaver.com/ie-en/media-and-downloads/news-detail/the-future-of-waste-to-energy/

- Bord Na Mona & BOC[6] are planning a 2 MW pilot electrolyser at its Mount Lucas wind farm in County Offaly to test the co-location of wind generation and electrolysis.
- Mercury Renewables are applying for planning permission for a wind farm and 80 MW hydrogen electrolyser in Mayo following a study with MaREI and DCU to assess the use of green hydrogen in transport (DECC, 2022a).
- ESB Generation is developing the "Green Atlantic at Moneypoint"[7] project, which includes plans for a 1,400 MW floating offshore wind farm and a green hydrogen production, storage, and generation facility by the end of 2030.
- EI-H2[8] are applying for planning permission for a 50 MW electrolysis plant in Aghada, Co. Cork, with the site chosen due to its proximity to Whitegate and other heavy industry. The project aims to use surplus renewable electricity, particularly offshore wind, to produce hydrogen.
- An EU-funded research project ("GenComm") has proposed a pilot 500 MW electrolysis and generation plant in Northern Ireland[9].

In terms of pilot projects for hydrogen demand, the pilot project using hydrogen-fuel-cell-electric buses on commuter services in the Greater Dublin Area is discussed in Section 4.3 and hydrogen blending in the natural gas network is discussed in Section 5.3.

1.2. EU and International use of Hydrogen

Global hydrogen demand was circa 94 million tonnes in 2021, an increase of 5% in 2020, driven by the chemicals and refining sectors (IEA, 2022). Most of the hydrogen is currently produced from fossil fuels or as a by-product from industrial processes. Low-emission hydrogen production was less than 1 Mt (0.7%) in 2021, almost all from fossil fuels with CCUS, with only 35 kt of hydrogen produced from electricity via water electrolysis[10].

Hydrogen currently accounts for less than 2% of the EU's energy consumption and is used in industrial processes including oil refining, production of ammonia and methanol production (DECC, 2022a).

Estimates of future worldwide hydrogen demand vary significantly. The International Renewable Energy Agency (IRENA) estimates that in order to achieve the Paris agreement, around 8% of global energy consumption will be provided by hydrogen (IRENA 2020).

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[6] BOC Ltd is a British based multinational, industrial gas company, more commonly known as BOC, now a part of Linde plc. a global multinational chemical company.

[7] https://esb.ie/what-we-do/generation-and-trading/green-atlantic-at-moneypoint

[8] https://eih2.ie/e120m-green-energy-facility-planned-for-cork-creating-85-jobs/

[9] https://www.nweurope.eu/projects/project-search/gencomm-generating-energy-secure-communities/

[10] A kilogramme of hydrogen has an energy value of circa 33.3 KWh, with a tonne of hydrogen delivering circa 33 MWh and a million tonnes delivering circa 33 TWh.

However, a number of predictions suggest that hydrogen could account for approximately 20% of final energy demand by 2050 (International Energy Agency, 2022) while others suggest up to 24%[11] by 2050.

2. Review of EU Hydrogen Strategies and Targets

As the potential for green hydrogen has developed, a number of countries have developed hydrogen strategies and studies have been carried out by the International Energy Agency, International Renewable Energy Agency and others on the potential for hydrogen to support decarbonisation of energy systems. A number of these studies are referenced in this discussion paper or included in the References section below.

The World Energy Council (2021c) has noted that there are significant divergences in national hydrogen strategies across countries and regions, determined by individual country contexts. The World Energy Council (2021b) has also recommended a well-defined national strategy as a key enabler of hydrogen development along with national support to facilitate local supply and demand.

The IEA's 2021 study on Hydrogen in Northwest Europe has observed that different hydrogen strategies build on national contexts such as existing hydrogen demand centres or offshore energy potential. A common focus is on hard-to-abate emissions, particularly in industry. Additional potential roles for hydrogen identified in several strategies include heavy transport, residential heating and energy trade/exports.

Table 1: *An overview of a selection of hydrogen strategies in the EU*

Hydrogen Strategy	Target	Supply	Demand
EU	6 GW renewable hydrogen electrolysers by 2024, 40 GW by 2030 (European Commission, 2020).	The priority for the EU is to develop renewable hydrogen, produced using mainly wind and solar energy. This is envisaged through large scale wind and solar plants dedicated to	In the first instance, the priority is decarbonisation of existing hydrogen production such as in the chemical sector. New end use applications for hydrogen are identified including steelmaking, trucks, rail and

[11] James Carton (DCU), Oireachtas Committee on Environment and Climate Action, https://data.oireachtas.ie/ie/oireachtas/committee/dail/33/joint_committee_on_environment_and_climate_action/submissions/2022/2022-03-01_opening-statement-dr-james-carton-assistant-professor-energy-sustainability-and-hydrogen_en.pdf

	Further deployment from 2030 across all hard to decarbonise sectors.	renewable hydrogen production. In the short and medium term, however, the strategy states that other forms of low-carbon hydrogen are needed, primarily to rapidly reduce emissions from existing hydrogen production within the EU and support future uptake of renewable hydrogen. The strategy also aims to bridge the cost gap between conventional solutions and renewable and low carbon hydrogen through appropriate State Aid Rules.	some maritime transport applications, other transport modes and heating applications. Renewable hydrogen will start playing a role in balancing a renewables-based electricity system by transforming electricity into hydrogen when renewable electricity is abundant and cheap and by providing flexibility. Hydrogen will also be used for daily or seasonal storage, as a backup and provide buffering functions.
Germany	5 GW capacity by 2030 and further 5 GW by 2035 (German National Hydrogen Strategy, 2020).	The strategy states that Hydrogen produced by renewable energy is the only sustainable option in the long term. Under the strategy, Germany is likely to require hydrogen imports given its limited renewable energy generation capacity.	The strategy identifies hydrogen as an energy source, energy storage medium and as an input to chemical and industrial processes. Currently hydrogen is an important base material for the German industrial sector and the strategy envisages use in the industrial sector, transport and heat.

			In Germany, the emphasis is on chemical, petrochemicals and steelmaking industries together with a focus on heavy-duty vehicles such as military vehicles, haulage and buses.
UK	**UK:** 1 GW of low carbon hydrogen production capacity by 2025, 5 GW by 2030 (UK Hydrogen Strategy, 2021). In 2018 the UK CCC produced a report on 'Hydrogen in a low-carbon economy'[12]	The **UK strategy** focuses on green hydrogen and CCUS enabled blue hydrogen.	The **UK strategy** includes trials of hydrogen use in heat in neighbourhoods and a final decision on its use in heating by 2026. A decision on use in HGVs is signalled for the mid-2020s.
	Scotland: 5 GW of renewable and low-carbon Hydrogen by 2030 and 25 GW by 2045 (Scottish Draft Hydrogen Action Plan, 2021).	**Scotland's** Hydrogen Assessment Project envisages establishment of Scotland as a hydrogen exporter to Europe using offshore wind to produce green hydrogen, but initially involves investment in blue hydrogen projects.	**Scotland's** draft hydrogen action plan envisages Scotland as a major green hydrogen exporter through repurposing of oil and gas pipeline infrastructure, with use in the domestic market in buildings, industry and transport.
Portugal	2 GW capacity by 2030, 5 GW by 2050 (Portugal National Hydrogen Strategy, 2020).	Focusing on the production and domestic consumption of renewable hydrogen, with longer term export aims.	The focus of the strategy is on transport and industry. The strategy aims for 20% hydrogen consumption in the road transport sector by 2050.

[12] https://www.theccc.org.uk/wp-content/uploads/2018/11/Hydrogen-in-a-low-carbon-economy.pdf

Ireland proposed Strategy	TBC (DECC, 2022a). 2 GW of offshore wind capacity for hydrogen production by 2030 noted as part of the increased target for offshore wind agreed with the Sectoral Emissions Ceilings. NCAP 2021 included a target of delivery of 1-3 TWh of zero emissions gas (including green hydrogen) by 2030	Focused on hydrogen production through renewable electricity as significant scale offshore wind capacity is developed.	Potential to support decarbonisation where energy efficiency, electrification and direct use of renewables are not feasible, including in heavy goods transport, high-temperature heat for industry and in electricity generation as a back-up for intermittent renewables. The strategy identifies an export opportunity for hydrogen in the medium term.

3. Potential Hydrogen Supply in Ireland

A number of studies (e.g., Gunawan et al. 2020, Farrell 2022 and Longoria et al. 2022) and the recent Consultation for developing a hydrogen strategy for Ireland (DECC, 2022a) have identified the opportunity for hydrogen production in Ireland using renewable electricity, in particular based on Ireland's significant offshore wind resource. The location, scale and method of hydrogen production is dependent on several factors including the availability of excess renewable electricity, grid access and location of appropriate storage and demand sites.

SEAI's 2022 Heat Study has considered a number of potential pathways for hydrogen based on production from renewable sources, finding that green hydrogen produced using bioenergy[13] and wind-generated renewable electricity is unlikely to be available at scale until the 2030s. However, within the 2020s, there may be a role for the initial development of green hydrogen with dedicated wind generation in parts of the country where the capacity of the electricity transmission grid is limited, for example in the Northwest of Ireland.

In the medium term, the study identifies significant opportunity for green hydrogen production using electricity generated from floating offshore wind. SEAI's Heat Study estimates that over 90 TWh of hydrogen production per year may be possible based on Ireland's offshore wind

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[13] The draft delegated regulation under the Renewable Energy Directive 2018/2001 (RED II) currently defines renewable hydrogen within Art 2(4): '*renewable hydrogen' means hydrogen derived only from renewable energy sources other than biomass*". While this is still under negotiation, it seems that the focus for renewable hydrogen will be production using renewable electricity.

energy resource. This is significantly greater than the target of identifying a route to deliver 1-3 TWh of zero emissions gas by 2030.

A large-scale rollout of onshore and offshore renewable electricity generation is expected by 2050 in line with decarbonisation efforts. If the 2030 target of 80% renewable electricity is to be met this will require significant rollout of renewable electricity generation within this decade.

Wind Energy Ireland (2022) estimates that if all announced capacity is energised, Ireland can expect to produce up to 42.7 TWh of renewable electricity per year by 2030, with overall electricity demand expected to increase to 46-56 TWh in the same period. In comparison, the Median Demand Forecast used in the latest EirGrid and SONI Generation Capacity Statement (GCS) shown in Table 2 below is 46.1 TWh in 2030 and the High Demand Forecast is 50.1 TWh. Table 2 includes an estimate of total wind and solar generation up to 2031 calculated using the data published with the GCS for comparison with Wind Energy Ireland's estimate. While there is some difference between both estimates (42.7 TWh versus 37 TWh), when this range is compared to expected electricity demand in both cases it suggests that there may be limited excess generation available for renewable hydrogen production within this decade.

Table 2: *Estimated potential for hydrogen production using excess renewable generation between 2022-2023*[14]

Ireland	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Median Demand Forecast (TWh)	33.7	35.7	37.5	38.5	39.9	41.3	42.7	43.9	45.1	46.1
Total wind and solar generation (TWh)	11	11	12	12	12	12	12	22	29	37
Estimated Dispatch Down (TWh) (excluding oversupply)	1	1	1	1	1	1	1	2	2	3

In terms of production utilising excess renewable generation, there may be 1-3 TWh of constrained and curtailed electricity available as an input for a grid connected electrolyser in 2030 (which does not include times when there is an oversupply of wind generation), however

[14] The median demand forecast is taken from EirGrid and SONI's 2021-2031 Generation Capacity Statement. Total available wind and solar generation is estimated based on GCS assumptions on installed wind and solar capacity between 2022-2031 and a capacity factor of 28% for onshore wind, 35% for offshore wind and 11% for solar generation. Higher estimates for capacity factors could also be used to account for technology development which would increase the numbers in Table 2. Estimated dispatch down (a combination of constrained and curtailed renewable electricity) is based on available renewable generation being constrained or curtailed by a total of 8% using 2021 and 2022 information but this could be subject to significant variation depending on the development of the grid and location of new generation capacity. This also does not account for periods of oversupply, where there is greater availability of wind generation than demand. NCAP 2023 includes a KPI to maintain dispatch down of renewables (excluding oversupply) below 7%.

there is a question of how this would be utilised and interact with the electricity system, where an electrolyser in such a use case might be most appropriately located and the viability of an electrolyser with an annual load factor based on curtailed electricity.

This means that in the short term, any dedicated renewables used to produce hydrogen would have to compete with demand for renewables to supply electricity for the wider power sector, which may increase the cost of hydrogen (SEAI, 2022). The Consultation on Ireland's Hydrogen Strategy (DECC, 2022a) acknowledges this issue and proposes that efficiency losses through conversion of renewable energy to hydrogen should only be contemplated where this does not reduce the supply of renewable electricity to meet domestic electricity demand. The Consultation also recognises that further work is needed to understand how hydrogen production using renewable electricity interacts with the electricity systems needs and timelines for deployment of renewable capacity.

This approach is supported in a study by Ueckerdt et al. (2021) which recommends that any utilisation of renewable electricity for green hydrogen production needs to consider broader electricity system requirements and prioritise direct utilisation of renewable electricity to offset fossil use for electricity generation. This is particularly important in the near term where a growing renewable electricity share is needed to replace fossil fuel generation to meet existing electricity demand and to ensure that limited renewable electricity is used in the most efficient way. A further area for consideration beyond domestic demand for renewable electricity is the value of further interconnection for export of renewable electricity where feasible, versus its utilisation for hydrogen production and export. A recent paper by Mehigan et al (2022) notes that in the timeframe to 2030 it is essential that proven technologies such as interconnectors and batteries are deployed to provide additional system flexibility and ensure emissions reduce as quickly and efficiently as possible.

There is a clear challenge for green hydrogen production competing with direct electrification in the short term, however in the medium to longer term there is an expected renewable energy surplus compared to domestic Irish demand based on the rollout of significant offshore wind capacity.

There may be opportunity for some hydrogen production through utilisation of excess renewable electricity where it is curtailed (due to limitations on accommodating a high percentage of renewable electricity on the system) or constrained (where there are local network limitations on accommodating renewable electricity). However, there is a challenge in terms of whether the revenue associated with this method of production would be sufficient to cover the capital and operational expenditure of a co-located electrolyser with a lower capacity factor. The capacity of curtailed or constrained wind generation is a factor in the business case of electrolyser locations, as both electricity prices and the load hours of an electrolyser have a significant impact on production costs (discussed further in Section 6 below). A 2020 study by Gunawan et al. found that wind farm capacities lower than 5 MW are not suitable for co-located hydrogen production with curtailed wind only, wind farms below 1 MW are not suitable for hydrogen production based on available wind, and wind farms below 0.1 MW are not suitable even when the electrolyser is operating at full capacity.

There is also a need to identify the most appropriate locations for development of electrolysers and to understand how they can be scheduled and dispatched within the electricity system, as they could place large loads/demands on the system if they are producing hydrogen using grid electricity (DECC, 2022a). In their response to the DECC Consultation on Developing a Hydrogen Strategy for Ireland, NexSys has identified a number of requirements to develop a supply of green hydrogen through renewable offshore wind including the mapping of potential offshore locations and how they might integrate into the wider energy system, identification of suitable offshore and onshore locations to develop hydrogen infrastructure and the evaluation of potential routes to market.

At a high level, there are four main production methods identified for production of green hydrogen using renewable electricity with an electrolyser (See Table 3 below).

Table 3: *The four main production methods of green hydrogen using electricity*

Production from the grid	**Production from on-site renewables**
Electrolysis using grid-connected electrolysers to produce hydrogen using electricity from the grid during periods of generally lower electricity demand and electricity prices, with a higher capacity factor than using only curtailed/constrained RES (this will depend on a system with a high penetration of renewables in order to produce hydrogen which can be classified as green/renewable). Grid-connected hydrogen production would cause significant additional electricity demand on the grid, and so this hydrogen production method is expensive and would need to be flexible. This would also require a	**Grid connected with dedicated on-site renewables to supply power for electrolysis**, potentially providing system services and excess generation back onto the grid through combustion of hydrogen. This would involve the development of renewable electricity generation specifically to produce hydrogen through co-located electrolysers (as discussed, in the short to medium term this may compete with the development of renewables for direct electrification and flexibility of electrolysis demand and provision of system services may be important). This can be produced

high overall share of renewable electricity generation (see the discussion on EU definitions of green hydrogen below).	using fixed or floating offshore wind turbines, onshore wind turbines or solar PV.
Electrolysis using grid-connected electrolysers and running on curtailed RES from the grid only. While this has potential in the short term, there is a risk that relying purely on curtailed renewables would not allow the production plant to achieve a sufficient annual load factor to be economical.	**Non-grid connected with dedicated on-site renewables and hydrogen storag**e (as discussed, in the short to medium term this may compete with the development of renewables for direct electrification). This approach is also linked to the development of legislation to facilitate direct lines/private wires which is not provided for under the Electricity Regulation Act[15] (Piper response to DECC, 2022).

A consideration in relation to the production method is compliance with current EU definitions of green hydrogen[16]. This requires either (1) a direct connection between the hydrogen production unit and the electricity generating unit or (2) if produced using electricity taken from the grid, in order to be counted as fully renewable the average proportion of renewable electricity must have exceeded 90% on the grid in the previous calendar year. In relation to curtailed electricity, electricity taken from the grid and used to produce hydrogen at times of imbalance when renewable resources would otherwise have to be curtailed qualifies as clean hydrogen. There are other criteria to ensure additionality of renewable generation for hydrogen production (i.e., to reduce competition with renewable generation to supply electricity demand). This is based on the objective to either incentivise the deployment of new renewable electricity generation capacity or make use of existing excess renewable generation, in order to ensure that electrolysis-based hydrogen production does not displace renewable generation needed for decarbonising the electricity system.

Another consideration related to these production methods is the stability of supply of hydrogen which is related to the development of adequate storage for different demand vectors (discussed in Section 5.2). Renewable hydrogen relies on the supply of electricity from renewable resources which can be impacted by weather fluctuations and sufficient storage

[15] The Climate Action Plan 2021 includes a commitment to review the policy position on the development of private networks/direct lines (Action 115)

[16] See: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/7046068-Production-of-renewable-transport-fuels-share-of-renewable-electricity-requirements-_en

will be required to mitigate uncertainty with the stability of renewable hydrogen supply (World Energy Council, 2021c).

The EU hydrogen strategy notes that larger size, more efficient and cost-effective electrolysers (in the range of gigawatts) will be required to supply hydrogen to large consumers. Solutions at lower technology readiness level for renewable hydrogen production such as more efficient electrolysers also need to be incentivised and developed. The IEA (2022) has found that the average plant size of new electrolysers commencing operation in 2021 was 5 MW while the average size of new plants could be around 260 MW in 2025 and in the GW-scale by 2030.

A 2021 study by Gunawan et al. also found that the integration of wind electricity with solar electricity and battery usage increases productivity of an electrolyser compared to only using wind electricity, with batteries storing PV outputs and surplus curtailed wind if production is limited by electrolyser size. The IEA (2022) also states that hybrid plants with different renewable resources such as PV and wind generation can increase annual load hours and increase hydrogen supply, with batteries used to balance variability. Using offshore wind generation for electrolysis is another option to provide hydrogen at relatively high annual load factors, with lower costs of green hydrogen output with higher availability of renewable electricity inputs.

SEAI's Heat Study also considered the potential renewable electricity generation resource available to produce green hydrogen, shown in Table 4 below.

Table 4: SEAI assessment of renewable electricity production capacity beyond what is planned for electricity network connection. Source: Table 6, SEAI National Heat Study Low Carbon Gases for Heat

Renewable generation type	Total potential additional capacity	Capacity for grid connection	Capacity potentially available for H_2 generation* *(i.e. not connected directly to the grid)	Average capacity factor (%)[17]	Earliest technology availability
Onshore wind	6.3 GW	1.7 GW	4.6 GW	40%	Available now
Fixed offshore wind	5 GW	3.3 GW	1.7 GW	50%	Available now
Floating offshore wind	20 GW	1.4 GW	18.6 GW	55%	2035
Solar PV	3.4 GW	1.4 GW	2 GW	11%	Available now

[17] The capacity factor of different generation types is the ratio of average electricity produced to the theoretical maximum possible if the installed capacity was generating at a maximum for a full year.

The IEA (2022) also notes that developing industrial supply chains for electrolysers[18] will be critical for low-emission hydrogen to support the roadmaps and strategies that have been recently developed by Governments.

3.1. Hydrogen Standards

It will be important with any significant uptake of hydrogen to ensure appropriate standards are in place across the EU and to ensure the sustainability of supply chains. The World Energy Council has noted that there is a need to assess the full carbon equivalence of different hydrogen production methods with some confusion over 'colours' across the policy and literature in this area. Standards and certification mechanisms will help to harmonise hydrogen development and support cross border trade (World Energy Council 2021b).

A comparison of hydrogen production based in its carbon intensity – expressed in tonnes CO_2eq per ton of hydrogen produced – is a potential way to assess the emission footprint of different production mechanisms. The recent EU Taxonomy[19], a classification system establishing environmentally sustainable economic activities, states that a carbon intensity benchmark of 3 tCO_2eq/tH_2 is required on a lifecycle basis[20] for hydrogen production to be classified as an environmentally sustainable economic activity (World Energy Council 2021b). This compares to a current global average carbon intensity of hydrogen production of nearly 10 tCO_2eq/tH_2 in 2020[21].

The National Standards Authority of Ireland is also currently considering new standards that will be required for hydrogen, for example for repurposing of existing natural gas distribution pipelines and adaption of existing Irish gas standards (NSAI, 2022).

4. Potential Hydrogen Demand in Ireland

In addition to supply of hydrogen, there is a need to explore the development of hydrogen infrastructure and supply chains, which is acknowledged in the EU Hydrogen Strategy among others. This is particularly the case in Ireland where there is a low level of industrial activity for

[18] Alkaline electrolysers dominate today with a share of 60% global manufacturing capacity, reflecting the maturity of the technology compared to PEM and SOEC electrolysers.
[19] https://ec.europa.eu/sustainable-finance-taxonomy/taxonomy-compass
[20] Lifecycle GHG emissions savings are calculated using the methodology referred to in Article 28(5) of Directive (EU) 2018/2001 or, alternatively, using ISO 14067:2018 or ISO 14064-1:2018
[21] https://www.iea.org/reports/hydrogen-supply

the initial development of hydrogen (Laguipo et al. 2022). Initial policy support may be needed to help create a market for hydrogen as a fuel and energy vector.

As shown in Section 2, a number of common hard to abate sectors have provided the focal point for potential hydrogen uptake in hydrogen strategies, including heavy duty and long-distance transport applications (buses, trucks, etc.) and carbon-intensive industrial sectors that already require and consume fossil fuel derived hydrogen (refineries, fertilisers, steel) (World Energy Council 2021b).

The demand for hydrogen across different sectors will depend on the development of competing technologies and mitigation solutions such as energy efficiency, electrification, carbon capture, and the costs and efficiencies of hydrogen technologies (World Energy Council 2021a).

A study by Laguipo et al. (2022) identifies two demand pathways for green hydrogen, firstly by replacing current supplies of hydrogen in existing applications with green hydrogen and secondly by using green hydrogen in new applications where its potential has not been well established. In the sectoral demand sections below (Section 4.1-4.3), alternatives to hydrogen are noted where they are available and summarised in a table for each sector. Policies to steer specific uses of hydrogen should account for the opportunity costs of using electricity and hydrogen elsewhere and a study by Ueckerdetal et al. (2021), suggests that hydrogen should be prioritised for sectors in which direct electrification or other mitigation options are impractical.

There are also potential export opportunities for green hydrogen. SEAI's Heat Study notes that if there is international demand for green hydrogen at the prices above circa 20 c/kWh there could be potential for development of an export market in the longer term. Section 6 discusses the cost of renewable hydrogen compared to other forms of production further.

4.1. Electricity Sector

Green hydrogen has potential application in the electricity system through production at times of surplus renewable electricity, for example through utilising curtailed electricity for production in the short term, and as a form of storage during times of low renewable electricity supply in the long-term. This has potential to enable Ireland to meet a greater share of its energy requirements using indigenous renewables and could support improved security of supply.

Long-duration storage provides system security by ensuring power that is produced when electricity is abundant can be stored for times when demand is high and renewable generation availability is limited. At times when there is an oversupply of electricity this could potentially be used to produce hydrogen. A recent ESRI paper (Longoria et al, 2022) notes that hydrogen produced via electrolysis can assist in energy diversification by balancing the variability of renewable energy availability and by providing ancillary system services which can also enhance profitability of green hydrogen production.

There is significant potential for hydrogen use as a vector for renewable energy storage, along with batteries and other forms of storage and a number of studies such as Mayyas et al. (2020) have demonstrated this potential. The recent Consultation on the Development of a Hydrogen Strategy notes that hydrogen as a method of storing electricity from variable renewable generation may be needed to address the challenges associated with system stability, seasonal wind variability and curtailment. Cyclical or seasonal storage is currently being explored for example in salt caverns (European Commission, 2020) and methods of storage are discussed further in Section 5.

SEAI's Heat Study found that generation and storage of hydrogen as a long-term storage mechanism in the power sector could potentially enable dispatchable power generation with low emissions. The study also notes that the sale of hydrogen to a range of consumers could provide an alternative revenue stream for owners of renewable energy generation sites.

DECC's recent Consultation on the Development an Electricity Storage Policy Framework for Ireland also notes the potential for use of hydrogen as a medium for the storage of electricity. However, it references the efficiency of using electricity to produce hydrogen for combustion in thermal electricity generation is likely to be less than 50%, even with significant technological breakthroughs. The efficiency reduces further if hydrogen is liquified or converted to ammonia for storage and transport.

The IEA (2022) notes that electricity generation technologies that can use hydrogen are commercially available today which are capable of running on hydrogen blends, with technologies that can run on 100% hydrogen due to become commercially available. A number of projects have been announced that plan to use increasing hydrogen blends in combined cycle or open cycle gas turbines, linked to hydrogen storage.

The design of electricity markets will be important to account for the gap between renewable hydrogen used for electricity generation and fossil fuel electricity generation though revenues associated with flexibility, capacity and system services provision along with carbon pricing (IEA, 2022). This could also be a relevant consideration in the development of terms and conditions under each Renewable Electricity Support Scheme (RESS).

Table 5: *Potential Electricity Sector Hydrogen Use Case and Alternative Technologies*

Potential Hydrogen Use Case	Alternative technologies

Long term energy storage and system balancing during periods of low wind and solar generation.	Limited, lithium-ion batteries currently only capable of providing short duration storage and while further electrical interconnection with other jurisdictions will be beneficial this will not support the energy system during extended periods of low renewable output. Further opportunities to develop pumped hydro storage, while valuable, are limited in Ireland. A number of longer duration storage technologies are referenced in DECC's Consultation on developing an Electricity Storage Policy Framework including redox flow batteries, compressed air energy storage, liquid air energy storage and sodium-ion batteries.

4.2. Enterprise Sector

In the enterprise sector, an immediate application of hydrogen in an EU context is to reduce and replace the use of carbon-intensive hydrogen in refineries, for the production of ammonia (mainly for use in nitrogen fertilisers), and for new forms of methanol production, or to partially replace fossil fuels in steel making (European Commission, 2020). The IEA (2022) notes that replacing fossil fuel-based hydrogen with green/renewable hydrogen for such applications presents low technical challenges as it is a like-for-like substitution. It states that ammonia and methanol production are two demand segments for which low-emission hydrogen offers the largest potential to substitute existing emissions-intensive industrial hydrogen production.

In the Irish context, the role of hydrogen in the Whitegate refinery could be considered. For example, Irving Oil and Simply Blue Group have signed a Memorandum of Understanding which will see the companies jointly exploring the development of a renewable energy hub at the Whitegate refinery including the potential production of green hydrogen and its use in the production of e-fuels for local and international markets[22].

[22] https://www.energyireland.ie/irving-oil-and-simply-blue-group-announce-plans-to-explore-renewable-energy-hub-in-ireland/

A number of SEAI's Heat Study scenarios consider hydrogen fuel use in the industry sector to produce high grade and medium grade heat in industrial manufacturing processes which may be challenging to electrify. The timing, availability and cost of hydrogen present barriers to its uptake, which are key considerations in the context of alternative pathways to net zero. Industrial applications, particularly with low or medium temperature mitigation options such as electrification, should be considered selectively (IEA, 2022).

There will also be other competing technologies to meet medium and high-temperature heat use, including electric technologies, biomass and carbon capture, utilisation and storage (CCUS) on sites with significant manufacturing process emissions (DECC, 2022a). For example, a recent study by Madeddu et al. (2020) based on a bottom-up analysis of energy use across industrial sectors in Europe found that 78% of industrial energy demand is electrifiable with technologies that are already established, while 99% electrification can be achieved with the addition of technologies currently under development. It notes however that the extent to which direct electrification will be deployed is uncertain and depends on relative technology costs, particularly in sectors including primary steel, chemicals and cement production.

Table 6: *Potential Enterprise Sector Hydrogen Use Case and Alternative Technologies*

Potential Hydrogen Use Case	**Alternative technologies**
Replacement for carbon-intensive hydrogen already in use in industry such as refineries, ammonia and methanol production and steel making, though this potential is limited in Ireland. Production of medium and high-grade heat in industrial manufacturing processes.	Due to the timing, availability and cost of hydrogen, other competing technologies for medium-high temperature heat such as electrification, biomass and CCUS may develop.

4.3. Transport Sector

A number of studies and hydrogen strategies identify the potential application of green hydrogen in hard to abate parts of the transport system as a complement to electrification. As in other sectors, the technology readiness for fuel cell propulsion and direct hydrogen combustion limits the potential rollout of hydrogen-based fuels in the short to medium term (Wind Energy Ireland, 2022).

As E-fuels and hydrogen are not primary energy sources and are subject to conversion losses during their production and utilisation, hydrogen also competes with direct electrification alternatives in transport (Ueckerdtetal 2020).

HGVs: Green Hydrogen fuel cell technology can potentially complement battery electric technology for the heavy-duty vehicle sector, particularly for longer distance freight movements where there may be an advantage over electrification (DECC, 2022a). For larger vehicles such as HGVs with greater distance requirements which are more difficult to electrify, hydrogen has several potential advantages in terms of range and refuelling (Wind Energy Ireland, 2022).

A study by Laguipo et al. (2022) proposes that heavy-duty vehicles can be used as a starting point to create a hydrogen market in Ireland. It notes that at present, options for the haulage industry to decarbonise are limited, with a number of recent studies showing the potential for cost competitive use of green hydrogen in this area. The study notes that the lack of commercial hydrogen refuelling infrastructure is a limiting factor for deploying hydrogen fuel cell heavy duty vehicles. The deployment of hydrogen refuelling stations would need to build on clear analysis of fleet demand for the location of refuelling infrastructure and different requirements for heavy-duty vehicles (European Commission, 2020).

Buses: The National Transport Authority and Bus Éireann carried out a study using three hydrogen-fuel-cell-electric double-deck buses on commuter services in the Greater Dublin Area as part of the Department of Transport's Low Emission Bus Trial[23]. The final report on this trial found that on a primary energy basis, fuel cell buses powered by hydrogen produced from 100% renewable electricity are as energy efficient as diesel hybrid buses, but if produced by grid electricity are comparable with older Euro IV and Euro V diesel buses (Byrne Ó Cléirigh Consulting, 2022). With increasing renewable energy penetration on the electricity grid, the overall efficiency of fuel cell buses powered by hydrogen produced from grid electricity would improve.

The study found limitations compared to electric buses due to the maturity of hydrogen as a transport fuel, cost and the lack of distribution infrastructure. The study noted that if the price of carbon increases and the cost of renewable hydrogen reduces, the cost benefit analysis for hydrogen fuel cell buses would improve. It noted that fuel cell buses offer greater operational flexibility than electric buses with longer travel distances and shorter refuelling times.

[23] https://www.gov.ie/en/press-release/fb42f-ireland-takes-next-step-in-testing-hydrogen-buses-in-transport-fleet/

A 2021 study by Gunawan et al. found that with an appropriately optimised hydrogen supply chain (based for example on optimal sized electrolysers, wind, solar PV and batteries and appropriately located hydrogen refuelling stations), the operational cost of fuel cell electric buses could be cost competitive with public buses fuelled by diesel by 2030.

Shipping and aviation: There is potential for use of hydrogen-based renewable hydrogen derived synthetic fuels in the maritime and aviation sectors to meet decarbonisation targets.

In the aviation sector, hydrogen can be used to produce synthetic fuels which can be used with existing aircraft technology but are less efficient or fuel dense than current fuels. The EU strategy notes that in the longer-term, hydrogen-powered fuel cells, requiring adapted aircraft design, or hydrogen-based jet engines may also constitute an option for aviation.

In the maritime sector, hydrogen fuels in shipping are expected to be competitive with fossil fuels by 2030 and have lower overall costs by 2040 (Wind Energy Ireland, 2022). Liquefied hydrogen can be combusted or used in a fuel cell for marine applications or used to produce ammonia for use as a maritime fuel. It is expected however that there will be significant costs to retrofit ships and construct refuelling infrastructure (Wind Energy Ireland, 2022).

The Shannon Estuary Task Force aims to examine the potential for the Shannon Region to develop sustainable aviation fuels availing of potential offshore renewable energy (DECC, 2022a).

Table 7: *Potential Transport Sector Hydrogen Use Case and Alternative Technologies*

Potential Hydrogen Use Case	**Alternative technologies**
Heavy duty vehicles or long-distance public transport and for hydrogen-based fuels in the shipping and aviation sectors.	Due to the timing, availability and cost of hydrogen, there will be competition for direct electrification alternatives and other alternatives such as biofuels.

5. Potential Hydrogen Storage and Infrastructure in Ireland

For all renewable methods of hydrogen production and use cases as discussed in Sections 3 and 4, there will be a need for both storage and transport of hydrogen to align with production requirements and demand. The actual infrastructure needs for hydrogen will ultimately depend on the pattern of hydrogen production and demand and on transport costs (ACER-CEER, 2021). This will also be needed to connect areas with resources for renewable hydrogen production with demand.

Hydrogen can be transported via networks (i.e., via pipelines) or via transport mechanisms such as shipping or road freight. Transport of hydrogen can be via pure gaseous or liquid hydrogen, or alternatively it can be bound in bigger molecules that are easier to transport (e.g., ammonia or liquid organic hydrogen carriers such as dibenzyl toluene). Hydrogen can also provide cyclical or seasonal storage, e.g., in salt caverns, to produce electricity to cover peak demand, secure hydrogen supply, and allow electrolysers to operate flexibly (European Commission, 2020).

The cost of hydrogen infrastructure will depend on location of supply and demand, the technologies used, and access to finance with significant risks associated with the development of large-scale infrastructure. This includes for example the risk of stranded assets if alternative decarbonisation solutions develop (World Energy Council 2021b). In its hydrogen strategy for a climate-neutral Europe, the European Commission states that a condition for the widespread use of hydrogen as an energy carrier in the EU is the availability of energy infrastructure for connecting supply and demand.

In relation to infrastructure for electricity storage, ESB Networks' National Network, Local Connections programme identified locations where storage represents the only flexible technology capable of meeting the capacity needs of an energy system with additional renewable generation and increased electricity demand from transport and heating[24].

5.1. Infrastructure

The co-location of production and consumption of hydrogen (for example through hydrogen valleys[25]) could limit the initial need for investment in long-distance transport infrastructure and potentially be more cost effective, however advance planning for infrastructure requirements will be needed. The World Energy Council estimates that it could take a similar amount of time to implement hydrogen infrastructure as to plan and build a natural gas pipeline or LNG terminal, i.e., in the order of 10-15 years. It recommends that priority should be given to quick win projects and repurposing of existing infrastructure where possible. For example, if hydrogen is distributed in the form of ammonia this could enable the repurposing of some existing oil infrastructure to reduce costs, while natural gas pipelines could be repurposed to distribute hydrogen.

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[24] https://www.esbnetworks.ie/docs/default-source/publications/esb-networks-national-network-local-connections-programme-power-system-requirements(2).pdf?sfvrsn=1d0fcdde_3

[25] A hydrogen valley is essentially a project that clusters several industrial and research initiatives to carry out pilot projects across the complete hydrogen value chain (production, transport, distribution, and end use potentially including storage).

Wind Energy Ireland's 2022 report on port infrastructure notes that green hydrogen is likely to be proposed at port locations in relative proximity to offshore wind farms, which will provide additional competition for landside area and exacerbate current port capacity issues. Timely development of policy is recommended to provide the roadmap to allow for developers and port authorities to plan for the future.

In their response to the recent consultation on a National Hydrogen Strategy, the EPA noted that spatial planning considerations will need to incorporate adaptation and resilience planning for green hydrogen infrastructure which may be located in coastal locations with risks from rising sea level and increased magnitude and frequency of extreme events such as waves surges and flooding.

5.2. Hydrogen Storage

Hydrogen can be stored chemically through reaction with other elements or compounds and stored as a liquid or solid, however energy is required for conversion to the storage medium and reconversion to hydrogen which can significantly increase costs for final consumption.

Another method of storage is as a gas using pressurised containers. Hydrogen can also be stored as a gas in significantly larger volumes in geological formations, where underground caverns are built to store large volumes of hydrogen under pressure. Salt caverns, salt aquifers and depleted gas fields can be used for this purpose but due to the small size of the hydrogen molecule and its chemical and biological reactivity this is a challenging process and underground storage of hydrogen systems and associated knowledge are still in their infancy (DECC, 2022). In terms of geological storage, there is some known potential in the form of salt caverns at Islandmagee in Northern Ireland.

DCarbonX and ESB recently signed a joint venture agreement[26] to assess and develop offshore large-scale subsurface storage for green hydrogen, focusing on three specific green hydrogen storage opportunities based around proposed decarbonisation clusters – east of Dublin's Poolbeg, west of ESB's Green Atlantic at Moneypoint project and south of Aghada in Cork.

The former Kinsale Head gas field off the coast of Co. Cork is currently being assessed for Hydrogen Storage in Ireland. ESB and dCarbonX are undertaking an integrated project to develop large-scale storage for green hydrogen at the depleted Kinsale gas field reservoir[27].

[26] https://esb.ie/media-centre-news/press-releases/article/2022/09/05/esb-and-dcarbonx-expand-irish-offshore-energy-storage-partnership
[27] https://esb.ie/media-centre-news/press-releases/article/2021/08/12/esb-and-dcarbonx-launch-kinsale-head-hydrogen-storage-project

The project is pending licence and planning approvals but could have the potential to store up to 3 TWh of green hydrogen and hydrogen carriers.

SEAI's Heat study states that as Ireland has little known opportunity for geological storage of hydrogen, it may require significant volumes of hydrogen to be stored using other methods which would present a significant infrastructure requirement (SEAI 2022).

Hydrogen infrastructure may include many elements in the long-term including pipelines, compressors, trucks, ships, liquefaction and conversion plants, storage tanks and underground storage facilities (IEA, 2022).

5.3. Potential Use of Natural Gas Infrastructure in Ireland

The EU hydrogen strategy suggests that the existing gas grid could be partially repurposed for the transport of renewable hydrogen over longer distances and the development of larger-scale hydrogen storage facilities, but that a technical suitability assessment and further research is required to inform infrastructure planning through the Ten-Year Network Development Plan process. ACER's 2021 Market Monitoring Report notes that while there has been a discussion on the most appropriate strategy to foster a hydrogen market, either by developing dedicated infrastructure for pure hydrogen of mixing hydrogen with natural gas in the current network, the market is leaning towards backing the use of pure hydrogen infrastructure with the development of hydrogen production and demand in industrial clusters in EU Member States.

Ireland's gas distribution network is comprised of polyethylene pipes and early indications are that it is already capable of transporting hydrogen which may provide an opportunity for repurposing parts of the network for storage and transport of hydrogen (DECC 2022a). The IEA's 2022 Global Hydrogen Review suggests that repurposing of natural gas pipelines for the transmission of hydrogen can cut investment costs by 50-80% relative to the development of new pipelines. For example, German gas pipeline operators are planning to build a hydrogen grid, which would mostly be based on converted former natural gas pipelines and would link hydrogen consumption centres to green hydrogen production projects in Northern Germany[28].

There are a number of different views on blending a percentage of hydrogen into the natural gas network in Ireland. The proposed regulation regarding the EU Hydrogen and Gas Markets Decarbonisation Package states that Transmission System Operators shall accept gas with a hydrogen content of up to 5% at interconnection points between Member States from 1st

[28] H2 launch network 2030 (from the GDP Gas 2020-2030) - FNB GAS (fnb-gas.de)

October 2025. While Ireland's gas network is not directly connected to a Member State, it is connected indirectly via the UK (which has confirmed that it will align with this ambition) (DECC 2022a). The UK's hydrogen strategy also commits to hydrogen blending within the existing gas network and given Ireland's interconnection with the UK this is an area that needs to be considered. A decision on blending up to 20% of hydrogen into parts of the UK natural gas network is due to be taken in 2023.

Blending a percentage of hydrogen in the natural gas network is less efficient and may affect the design of gas infrastructure, end-user applications, and cross-border system interoperability. SEAI's Heat Study found that reliance on low carbon gas such as hydrogen for significant decarbonisation of heat has a number of risks based on the significant upfront investment required, competition with other decarbonisation options, lower efficiency compared to electricity and later potential uptake. The study found that within the 2020s, there may be a role for initial development of green hydrogen with dedicated wind generation in parts of the country where the electricity grid is limited but where access to the gas grid is available.

NexSys note in their response to DECC's Consultation that initial work to allow increased concentrations of hydrogen in the gas network will allow for accelerated development of a hydrogen market. This is also noted in Wind Energy Ireland's hydrogen report. It suggests that a blend of up to 20% hydrogen in existing natural gas pipelines could rapidly stimulate a domestic market. A 2020 study by Gunawan et al. also suggests that if produced at wind farms and transported to the gas network, hydrogen could be used to reduce wasted available wind energy and decarbonise the gas network. The IAE (2022) suggests that blending can be an interim strategy to trigger hydrogen production until the market grows sufficiently to justify the repurposing of existing gas assets or the construction of dedicated hydrogen pipelines.

6. Cost of Hydrogen in Ireland

The cost of hydrogen production depends upon the production method, the cost of fuel or dedicated renewable electricity generation, the requirements for hydrogen storage, and the costs to develop a hydrogen transmission network. Today, neither renewable hydrogen nor low-carbon hydrogen, notably fossil-based hydrogen with carbon capture, are cost-competitive against fossil-based hydrogen (European Commission, 2020). The key limiting factor for the use of hydrogen in industrial applications and transport is often the higher costs, including additional investments into hydrogen-based equipment, storage and bunkering facilities.

The high capital costs and long construction periods associated with hydrogen production and infrastructure, along with a lack of revenue certainty, means that there are significant investment risks associated with green hydrogen.

A 2022 study by Farrell found that hydrogen is most likely to be cost-effective post 2030, but that this is dependent on high degrees of capital cost reduction. Cost-effective deployment is most likely among transport, electricity storage and industrial applications. Many of the areas for which cost reductions may be achieved are associated with production process standardisation and economies of scale. Future electrolyser costs have been estimated by the IEA (2022) based on the current pipeline of planned projects, which will reduce capital costs by 60-64% by 2025 and by 68-72% by 2030.

Farrell's study also found that the pace of recent capital and electricity cost reductions suggests that electricity cost reductions may play a greater role in achieving cost-effective hydrogen production and that supporting cheaper renewable electricity is a no-regrets policy. While electrolysis has seen significant cost reductions the cost of green hydrogen is also highly dependent on the operating cost of the renewable electricity used. Cost declines for offshore wind power will greatly increase the viability of its pairing with electrolysis (Wind Energy Ireland, 2022).

SEAI's Heat Study estimates the long-run variable cost (LRVC) of green hydrogen to be 17-23 c/kWh. Most of the resource potential estimated is produced from floating offshore wind and falls at the high end of this range. This cost estimate includes inter-seasonal storage of hydrogen as ammonia and the costs of converting the gas networks to carry hydrogen and is shown in Figure 1 below. EirWind[29] results also show that final hydrogen costs to customers begin to look competitive with respect to petrol and diesel if a decarbonising subsidy is introduced.

[29] https://www.marei.ie/project/eirwind/

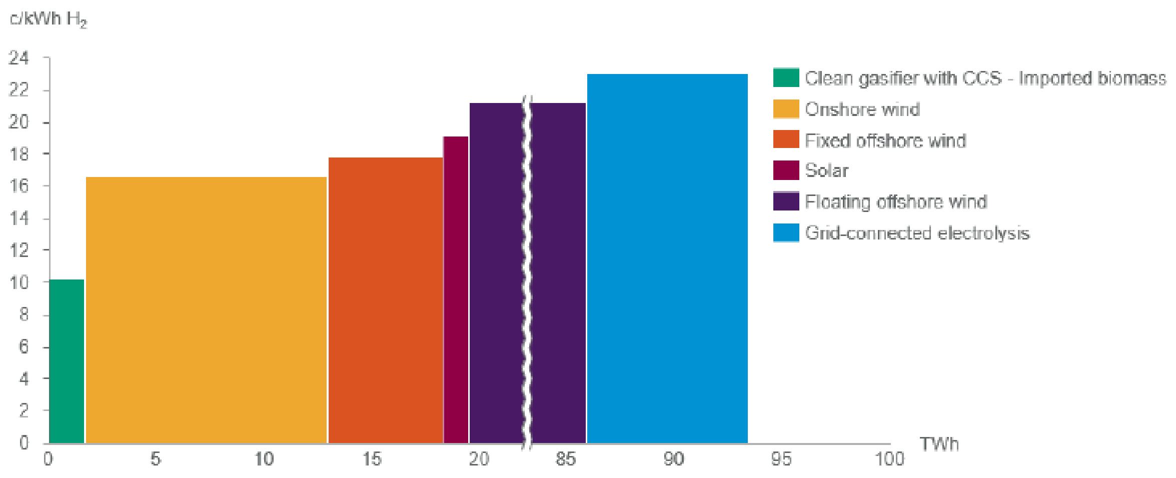

Figure 1: *LRVC of Hydrogen production in Ireland in 2050. Source: Figure 62, SEAI National Heat Study Net Zero by 2050*

The EU has created the European Clean Hydrogen Alliance to help build a pipeline of viable investment projects, which aims to coordinate investments and policies along the hydrogen value chain and promote cooperation across private and public stakeholders (World Energy Council 2021b). However, most national strategies are unclear about mobilising private investments while some suggest forms of support schemes for green hydrogen at the early stages of development, such as Contracts for Difference based support schemes (UK Government, 2021 and European Commission 2020).

The early stage of hydrogen markets, costs of production and lack of hydrogen infrastructure presents a number of barriers to development and financial feasibility. The development of a generation, storage and transportation network also presents a challenge and significant risk if alternative decarbonisation options become viable.

Ongoing research efforts are focusing on reducing electrolysis costs, enhancing how flexibly they can operate and improving overall efficiency. Further investigation into the availability of suitable geological storage in Ireland and into the development of liquid storage technologies could help lower the storage cost component of hydrogen fuel (SEAI, 2022).

Farrell's 2022 study recommended that the adoption of hydrogen as part of a decarbonised portfolio of technologies should be guided by technology-neutral policy targeted at specific market failures. To guide emissions reduction, the first-best solution is a target-consistent high and rising carbon price.

7. Emissions associated with Hydrogen

Reliable methodologies have to be developed for assessing the environmental impacts of hydrogen technologies and their associated value chains, including their full life-cycle greenhouse gas emissions and sustainability (European Commission, 2020).

7.1. Indirect GHG Impacts

While zero- and low-carbon hydrogen has a number of potential applications, hydrogen is also a short-lived indirect greenhouse gas (Ocko and Hamburg, 2022). A greater understanding of hydrogen's warming impacts at different possible leakage rates is critical to inform where and how to deploy hydrogen effectively. This is separate to the climate impacts from methane leakage when hydrogen is produced via natural gas with CCUS (blue hydrogen).

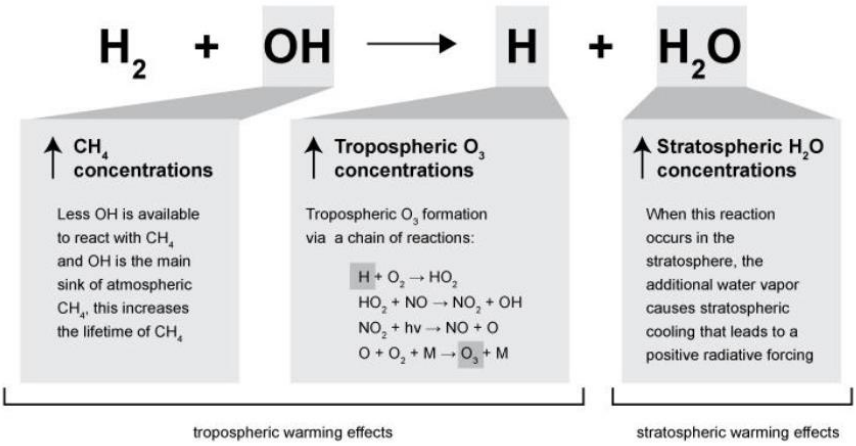

Figure 2: *Impacts of hydrogen in the atmosphere. Source: Ocko and Hamburg, 2022*

A recent study (Ocko and Hamburg, 2022) finds that hydrogen leakage may have the potential to considerably undermine near and mid-term climate benefits and recommends further work to advance understanding of hydrogen's indirect climate effects and improved estimates of hydrogen leakage throughout the value chain. It is also recommended that hydrogen should be deployed with minimisation of leakage, such as within hubs where hydrogen is produced and used with limited transport. A recent study investigating the potential for fugitive hydrogen emissions in a in a future UK hydrogen economy noted that there are likely to be hydrogen emissions across the hydrogen landscape from production, transport, and storage through to end-use applications (Frazer-Nash Consultancy, 2022). The overall magnitude of the short-term warming effects from hydrogen leakage will depend on how much hydrogen is deployed to replace fossil fuel systems and how much is able to leak from the value chain.

7.2. NOx Impacts

While hydrogen combustion for power generation does not produce CO_2 emissions, it produces other air emissions such as NOx through the thermal formation of nitrogen oxides which needs to be considered as part of its overall environmental impact (DECC, 2022a) (Lewis, 2021).

Hydrogen can be supplied to electrochemical fuel cells to directly generate electricity, which does not generate NOx as a waste by-product. However, fuel cell technologies have a more limited application history than combustion and require a greater degree of modification than existing combustion approaches to accommodate hydrogen (Lewis, 2021).

This is a particularly important consideration in the potential use of hydrogen in Ireland in large scale combustion for electricity generation, particularly in the conversion of new gas fired generation to hydrogen as has been stated in policy.

7.3. Ammonia emissions

If ammonia is widely used in Ireland as a storage method for hydrogen, ammonia emissions must be closely monitored to align with national emissions limits. The EU's National Emissions Ceilings Directive (2016/2284) gives emission limits for EU member states for several air polluting gases, including ammonia.

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