element energy

Green Gas in Transport Pathways for Ireland

Final Report

for

Gas Networks Ireland

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Executive Summary

Project Background, Aims and Objectives

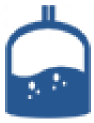
In 2021 Element Energy produced a report for Great Britain's Gas Distribution Network Operators (GB GDNOs) entitled 'The Future Role of Gas in Transport' which set out a narrative for the role of green gases (biomethane and hydrogen) to support and accelerate the decarbonisation of GB's energy system. Gas Networks Ireland were part of the steering committee for the project, and many of its conclusions are equally applicable to the Republic of Ireland (ROI) context. However, there are some key areas of difference and Gas Networks Ireland have commissioned this report as an addendum to the original GB-focused report to make clear where these similarities and differences lie.

The objectives of this study are to:

- **Investigate the key areas relevant to the narrative in the GB report to understand how they apply to ROI:** The GB report carried out analysis across the whole economy and set out a narrative for the role of electrification, biomethane and hydrogen to deliver decarbonisation. This report focuses on the key areas of the resulting narrative, to identify the role of green gases in trucks, and the potential for domestic production of green gases in ROI
- **Identify the key differences to the GB case:** The role of trucks to support early deployments of green gases is applicable in ROI, but the scale and mix of green gas production potential is quite different to that identified in GB. Biomethane from on-farm AD feedstocks makes up a larger proportional share of green gases in ROI, while ROI's lack of carbon storage potential means that blue hydrogen is unlikely to be produced in the country
- **Highlight the implications for the gas network in ROI:** One of the key differences in ROI is that the greater biomethane production potential, and the limited opportunities for carbon capture and storage (CCS) suggest that direct use of biomethane is likely to continue in the long term. However, the potential for domestic hydrogen production still outweighs biomethane and as a result the gas network in ROI will need to adapt to allow both gases to co-exist on the network into the long term

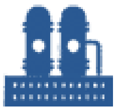
Green gases

This report discusses the potential future role of 'green gases' in ROI. The green gases referred to are biomethane and hydrogen, which can be produced using a variety of different technologies. This report refers to four main production routes for green gases:

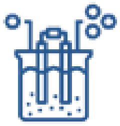


Biomethane from Anaerobic Digestion (AD): A mature technology for turning biological material into a non-fossil form of natural gas (methane). AD plants produce biogas which must then be upgraded to biomethane

Biomethane from Bio-Synthetic Natural Gas (Bio-SNG): This technology is at an earlier stage of development than AD but has the potential to unlock other feedstocks for biomethane production such as waste wood which are not suitable for AD plants



Blue Hydrogen: Hydrogen from reformation of natural gas which produces hydrogen and carbon monoxide. 90-95% of the carbon is captured and stored making this a low-carbon form of hydrogen.



Green Hydrogen: Water is split into hydrogen and oxygen via electrolysis using electricity generated by renewables. No carbon emissions are produced so this is zero-carbon hydrogen.

Key findings

There is a significant role for green gases to deliver early decarbonisation in ROI and for transport uses to support scale-up of production for wider use across the economy

Many of the conclusions of the GB report on the role of green gases in transport are applicable to the Irish case. If the current fuel duty differential is maintained at least until 2030, gas trucks in ROI could rapidly become a major source of demand for biomethane, supporting early decarbonisation in this segment before zero emission vehicles with battery electric or hydrogen drivetrains become available at scale. This is expected to be a 10-15 year 'window of opportunity', which makes it important to deploy biomethane production, injection and truck refuelling infrastructure rapidly in the short term to take advantage of this opportunity.

From the 2030s as zero emission options become available and begin to displace gas trucks from the fleet, there will be an opportunity for hydrogen trucks to create early demand for hydrogen as production ramps up across the country. As in the GB case, the infrastructure deployed for gas trucks will form a solid foundation for later hydrogen truck refuelling, and so support for gas trucks in the short term will support rather than hinder a later transition to hydrogen. Once hydrogen is established as a transport fuel for trucks, other vehicle segments will be able to take advantage of the existing infrastructure, making hydrogen a widely used transport fuel across the country.

The opportunity for biomethane is proportionately larger in ROI than in GB

This report has identified potential biomethane production in ROI of just under 14TWh, compared to 120TWh in the GB report. This is 2.7TWh of biomethane potential per million of population in ROI compared to 1.8TWh in GB suggesting that biomethane has a greater role to play within the mix of green gases than set out in the GB report. This is largely a result of agriculture making up a greater proportion of the Irish economy, and therefore greater opportunity for agricultural feedstocks to be used in AD plants for biomethane production.

The reverse is the case for hydrogen, where in GB 540TWh of production potential was identified (8TWh per million population) compared to 36TWh in ROI (7TWh per million population). This difference is driven by the expected contribution of large-scale blue hydrogen production from GB's domestic fossil natural gas resources and the opportunity for large scale reformation plants to be developed near to industrial users and capture and store the resulting carbon. In ROI, the opportunity for domestic hydrogen production is expected to focus exclusively on green hydrogen production from renewable electricity generation.

The direct use of biomethane to support decarbonisation has a longer-term role in ROI than in the GB case

The GB report highlighted that the direct use of biomethane in trucks and heating to achieve decarbonisation in these 'hard to decarbonise' sectors was likely to be a short to medium-term opportunity. After this, the gas network would transition to supplying 100% hydrogen, making it harder to transport biomethane from producers to consumers. Continued biomethane use beyond this point in GB would be most valuable in conjunction with CCS in order to deliver negative emissions and offset persistent emissions in other areas of the economy by 2050.

In the Irish case, there is a similar short-term opportunity for domestic production of biomethane to deliver substantial decarbonisation in heat and trucks which would otherwise only be possible in the 2030s when low and zero carbon alternatives become available at scale. However, as ROI has limited opportunities for geological storage of carbon, CCS is not expected to play a major role domestically, except perhaps in certain limited areas such as cement production as identified in the 2021 Climate Action Plan[1]. As a result, the injection of biomethane onto the Irish gas network for direct use across the economy is expected to continue out to 2050. Over this period, demand from gas trucks is expected to grow and then fall as zero-emission alternatives become available, but injection of biomethane into the network to decarbonise gas use across the economy is expected to continue into the long term.

Biomethane and hydrogen will need to co-exist on the Irish gas network

Over the next 10-15 years biomethane will be the main green gas injected to the network and because it is chemically identical to fossil natural gas this will not impact gas consumers. As green hydrogen begins to be produced at small scales it can be blended onto the network up to 20% by volume before consumer appliances would need to be changed. However, there is roughly two and a half times as much green hydrogen as biomethane production potential in ROI, so at some point in the late 2030s it will be necessary to convert at least some parts of the Irish gas network to supplying 100% hydrogen.

Because the producers and consumers of both gases will be dispersed across the country, and the potential volumes are so large, the gas network will play a vital role in transporting them cost effectively. In order to fulfil this role, the gas network will need to adapt over time to facilitate transportation of both gases. One option is for the 'main ring' of the transmission network to convert to 100% hydrogen, while the 'spurs' supplying individual regions or towns could supply whichever mixture of green gases is most appropriate depending on local production and demand.

Stakeholder actions

Gas trucks

Fuel duty differential: Providing certainty that the fuel duty differential between diesel and natural gas/biomethane will be maintained until at least 2030 will give truck operators the confidence to adopt these vehicles at scale. The UK government has committed to maintaining the fuel duty differential until 2032, subject to a review in 2024. Ensuring that there is a fuel cost benefit is essential to encourage the uptake of these vehicles which are

[1] Government of Ireland, 2021, Climate Action Plan 2021

more expensive to purchase than diesel vehicles and typically require vehicles to detour for refuelling which is less convenient that existing in-depot diesel refuelling practices.

Biomethane supply

Renewable Heat Obligation: Ireland's agricultural sector has significant potential to produce biomethane that can deliver short term decarbonisation of heating, a 'hard to decarbonise' sector for which zero carbon alternatives will not be cost effective and available at scale for many years. Setting the 'higher ambition' obligation rate for the proposed Renewable Heat Obligation would provide the necessary certainty for investors in this area, equating to ~5.3TWh of renewable heat by 2030. The EU recently doubled its ambition for biomethane production in response to the Ukraine conflict[2]. ROI would be starting from a very low base and so doubling the existing 2030 target of 1.6TWh[3] for biomethane injected into the network should be achievable. This means domestically produced biomethane could make a significant contribution to the higher ambition RHO target by 2030, while also supporting the decarbonisation of the truck fleet.

Biofuels Obligation Scheme: The Renewable Transport Fuel Obligation has been an effective measure in the UK to support the production of biomethane and its use as a transport fuel. A similar mechanism for ROI, such as the advanced biofuel obligation proposed in the 2019 Biofuels Obligation Scheme Consultation, would simultaneously stimulate the production and use of biomethane as a transport fuel for ROI. Gas-powered trucks are readily available and a scheme such as this is essential to ensure that there is sufficient biomethane available to fuel them as more are deployed on Ireland's roads.

Hydrogen trucks

Commercial demonstrations: Hydrogen truck trials are taking place across Europe and similar activities will need to take place in ROI by the mid-2020s to ensure hydrogen trucks can become a viable long term decarbonisation option for this segment.

Vehicle purchase support: The recently re-opened Alternatively Fuelled Heavy Duty Vehicle Purchase Grant Scheme[4] will likely prove an effective tool for encouraging purchases of CNG and LNG vehicles, while the fuel duty differential with diesel remains in place. However, as hydrogen vehicles become available, a grant covering 40-60% of the purchase price differential with conventional diesel vehicles is unlikely to be sufficient as these vehicles will initially be significantly more expensive than conventional vehicles. Additional support on purchase or fuel costs will be required initially to encourage fleets to adopt these vehicles early once they become available commercially.

End date for the sale of all trucks with tailpipe emissions: Setting an end date for the sale of all trucks with tailpipe emissions by 2040 will provide clarity for fleet operators and vehicle OEMs on the lifetime of investments in gas trucks, while making clear that the ultimate objective is to move towards pure battery electric and hydrogen models when these are commercially available.

Hydrogen supply

Large-scale green hydrogen demonstrations: ROI has significant green hydrogen production potential, which is likely to increase as further intermittent renewable electricity generation capacity is added in the coming years. Large-scale demonstration projects are

[2] European Commission, 2022, Factsheet - REPowerEU (europa.eu)
[3] Irish Government, Climate Action Plan, 2021, gov.ie - Climate Action Plan 2021 (www.gov.ie)
[4] Transport Infrastructure Ireland, 2022, Alternatively Fuelled HDV Purchase Grant Scheme - (tii.ie)

required in ROI in the 2020s to ensure that the supply chain and workforce are ready to scale up production in the 2030s. At this point, electrolyser manufacturers aim to have achieved significant cost reductions for equipment and ROI will need to have laid the foundations of a green hydrogen industry to be able to take advantage of these developments.

Contents

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Acronyms

AD	Anaerobic digestion
BECCS	Bio-energy carbon capture and storage
BEV	Battery electric vehicle
Bio-CH_4	Biomethane
Bio-SNG	Bio-synthetic natural gas
CCS	Carbon capture and storage
CH_4	Methane
CNG	Compressed natural gas
DfT	Department for Transport
GDN	Gas distribution network
GNI	Gas Networks Ireland
H_2	Hydrogen
HDV	Heavy duty vehicle
HGV	Heavy goods vehicle
HRS	Hydrogen refuelling station
LDV	Light duty vehicle
LNG	Liquefied natural gas
MSW	Municipal solid waste
PPA	Power purchase agreement
RTFO	Renewable transport fuel obligation

1 Introduction

1.1 Context of the report

In 2021, Element Energy produced a report for the GB GDNOs entitled 'The Future Role of Gas in Transport' which set out the role that green gases (biomethane and hydrogen) could play in accelerating the decarbonisation of GB's economy. Gas Networks Ireland was part of the steering committee for that project and was directly and actively involved in the production of the report, but the remit of the work was geographically limited to GB. Many of the conclusions of the report are applicable to both jurisdictions, though there are some key areas where the characteristics of ROI lead to different outcomes. Gas Network Ireland have commissioned this report as an addendum to the GB report, to make clear where these similarities and differences lie.

The original report developed a narrative for the role of the gas industry in GB over the next 30 years, setting out the role that it can play in delivering the 2050 net-zero target. The project was funded via the Future of Gas Network Innovation Allowance, which until the net-zero target was officially adopted in June 2019, had focused primarily on funding investigations into the role of green gases in decarbonising heat. With the increased level of ambition, it became clear that a range of 'hard to decarbonise' areas which had previously received little attention would need to be tackled. One of these areas is heavy duty trucks, and the report identified that green gases could play an important role in overcoming the challenges for this segment. The demand for green gases generated by gas-powered trucks could then play a role in supporting the scale-up of green gas production, helping to reduce costs and allowing them to play a wider role in decarbonising other sectors such as industry and heat.

This overarching story is also true in ROI. Like GB, ROI has a large fleet of long-haul heavy-duty trucks, and gas-powered vehicles are the only decarbonisation option that will be available to operators in the short term. As is the case in GB, the opportunity for gas trucks to deliver these benefits is 10-15 years, at which point battery electric or hydrogen models with sufficient capabilities are likely to become available at scale and will need to be adopted to achieve the deeper decarbonisation necessary by 2050.

As a result, the mix and role of green gases in ROI is likely to change over the next thirty years, and this is where the key differences with the GB situation lie. This report sets out scale of potential green gas production in Ireland, including the opportunities for biomethane production from agricultural and waste feedstocks, as well as green hydrogen from the ambitious growth in renewable electricity generation planned for Ireland in the coming years. This green gas production potential is compared with the findings of the GB report to highlight the implications for the gas industry in Ireland and the changing role of the gas network.

1.2 Approach and report structure

This addendum report sets out to identify the key differences for the role of green gases in ROI compared to the original GB-focused report. This is broken into 4 main sections:

- **The role of green gas in ROI:** This first section identifies the potential scale of demand for gases in ROI out to 2050 across the whole economy. This focuses on a quantification of the potential demand for biomethane from trucks which is not currently well understood in the Irish context as well as comment on the role of green gases in other sectors of the Irish economy

- **Biomethane production potential:** Examines the quantity of biomethane that could be produced in ROI, including an assessment of the biomethane that could be produced by on-farm AD plants using agricultural and waste feedstocks such as grass silage and animal slurry, and the potential for producing Bio-SNG via gasification of other waste feedstocks. Having established the scale of the potential, the implications of ramping-up production and transporting this quantity of gas is explored
- **Green hydrogen production potential:** This section looks at ROI's plans for increasing renewable electricity generation capacity and identifies the potential for producing green hydrogen with electricity that might otherwise be curtailed
- **The role of the gas network:** This section brings together the potential for green gas production in ROI identified in the previous two sections with the total gas demand in the first section. This provides an overview of how the decarbonisation of the gas network in ROI could play out over the next 30 years and explores how both biomethane and hydrogen could co-exist on the network

2 The role of green gas in Ireland

This section sets out the opportunities in ROI for biomethane to support early decarbonisation of trucks and support the later introduction of green hydrogen. As in the GB case, an early roll out of gas refuelling infrastructure for trucks is likely to support a later transition to hydrogen.

2.1 Green gas in transport

Electrification is already playing a significant role in decarbonising transport in ROI, with sales of electric cars growing rapidly, making up 8.3% of sales in 2021, nearly doubling the share the year before[5]. Even in heavier vehicle segments such as buses, substantial progress is being made, with the National Transport Authority announcing in 2020 that it would purchase 800 battery electric buses to be deployed by 2025[6]. Battery electric trucks are also expected to be an effective option for urban and regional deliveries and models are beginning to become available from manufacturers. However, roughly 45% of the Irish truck fleet is over 18 tonnes gross vehicle weight (GVW), which are either large rigid body vehicles or articulated trucks. These vehicles tend to carry the heaviest loads over the longest distances and development of battery electric or hydrogen models that are capable of these duty cycles are at an early stage of development.

Gas trucks running on methane on the other hand are already commercially available from several European manufacturers. There are around 140 gas-powered trucks on Irish roads currently and around 1,500 in GB, making up roughly 0.5% of the trucks over 18t in both countries. In ROI the fleet is supported by a network of four public and three private refuelling stations across the country. This number is set to grow with 9 further sites currently going through planning. This places both countries at roughly the same stage of deployment relative to the size of their fleets, suggesting that the opportunity identified in the GB report for gas trucks to contribute to substantial reductions in emissions over the next 10-15 years also applies to ROI.

As part of the analysis for this report, the same vehicle uptake model used for the GB report was applied to the Irish fleet to determine the number and type of vehicles that could be deployed in ROI by 2050 (the resulting fuel demand can be seen in the top chart of Figure 1). The key variables of the model are similar across GB and ROI, such as the expected supply of vehicles from European manufacturers, types of vehicles in the fleet, fuel costs and taxation regime. In the case of gas trucks, gas supplied to vehicles in ROI currently benefits from the same fuel duty differential compared to diesel as the GB regime. The vehicles typically cost €25,000 more to purchase and refuelling requires detouring to access public or shared refuelling infrastructure. As a result, the fuel duty differential is essential to make the business case for gas trucks work, but it also has the effect of incentivising the deployment of gas trucks on the highest mileage routes and therefore maximising the carbon emission reduction of each vehicle compared to a diesel equivalent.

The results of this modelling highlight that a peak of 9,500 gas powered HGVs could be deployed by 2035 before zero emission options become widely available in this segment. This would mean gas trucks making up 17% of the total HGV fleet in ROI, and roughly half of the >18t HGV fleet. With biomethane delivering emissions savings in excess of 80%[7]

[5] Irish Electric Vehicle Owners Association, 2022, [Over 8% of cars sold in 2021 were battery electric – Irish EV Owners Association – IEVOA]
[6] National Transport Authority, 2020, [NTA commences Procurement Process for up to 800 Electric Buses - National Transport]
[7] ZEMO Partnership (previously LowCVP), 2020, Low Emission Freight & Logistics Trial (LEFT) https://www.lowcvp.org.uk/assets/reports/LowCVP-LEFT_Dissemination_Report-2020.pdf

compared to diesel, this would represent a substantial early decarbonisation option for ROI, supporting the scale-up of a domestic biomethane production industry. Figure 1 shows that the fuel demands of a fleet of this size would be 3TWh of biomethane by 2035, which would require roughly 20 high-capacity refuelling stations to provide national coverage.

From 2035, demand for biomethane from trucks would likely begin to fall again as zero-emission alternatives become available for heavier vehicle segments. As in the GB case, the early rollout of refuelling infrastructure for biomethane trucks in ROI is expected to support the later rollout of infrastructure for hydrogen vehicles. This is primarily due to establishing a network of refuelling sites with a gas network connection and which are also conveniently located for use by HGV operators. There are a limited number of sites that meet these criteria and building out the network for gas trucks in the short term will ensure it is in place ahead of the deployment of hydrogen vehicles.

From the late 2020s as hydrogen trucks become available, some sites on the existing refuelling network could start to supply hydrogen supplied via tube trailers from local producers, alongside biomethane from the network. These sites would start small, supplying up to 1t/day of hydrogen and focusing on sites on the major road network and near to depot clusters to begin to provide national coverage. During the late 2030s as hydrogen trucks start to replace gas trucks in significant numbers, a small number of large-scale (over 3t/day) sites would need to be deployed to meet the demand.

These sites would be too large to supply by tube trailer and would depend on a supply from a gas network converted to 100% hydrogen. Hydrogen delivered via pipelines will pick up impurities which can damage fuel cells and so these large-scale sites would need to include purification facilities, which can have a significant additional footprint. However, such sites would be capable of processing more hydrogen than could be dispensed to vehicles from a single location and could act as ‘mother’ stations, supplying several smaller ‘daughter’ stations nearby. A summary of the timeline for this transition and how it would relate to other developments in the production and transport of green gases in ROI can be found in Chapter 7.

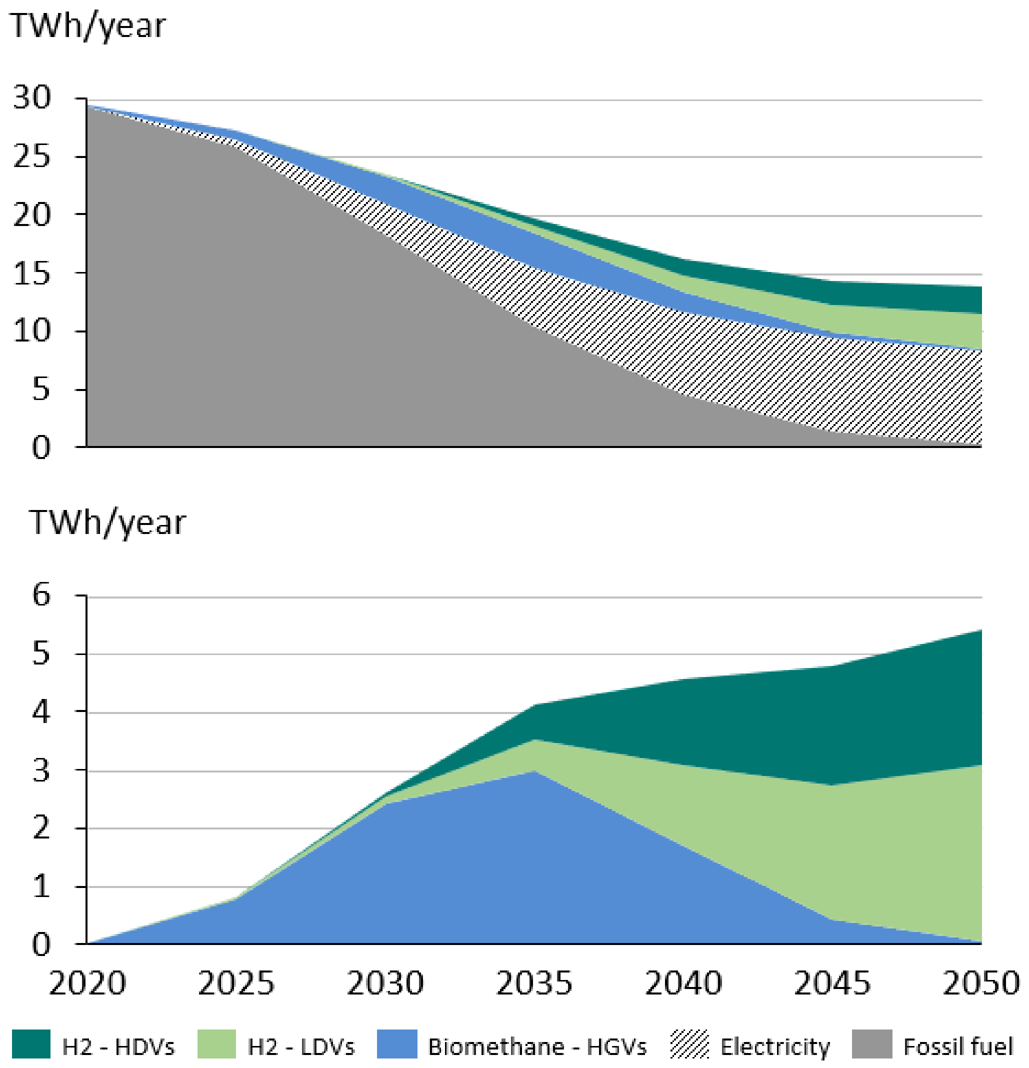

Figure 1 - All road transport fuel demand ROI (top) and green gas demand from transport ROI (bottom)

As national hydrogen refuelling coverage is achieved, the truck refuelling infrastructure could then act as a backbone to supply refuelling sites for light duty vehicles, helping to further increase demand for hydrogen. By 2035 transport demand for hydrogen could be over 1TWh/year, which would provide a significant source of demand for early hydrogen producers as projects begin to scale up. By 2050, most transport applications would have been electrified, but hydrogen could make up over 5TWh/year of demand in challenging, high mileage use cases such as heavy trucks and some lighter vehicles where rapid refuelling is essential. Hydrogen also has a role to play supporting decarbonisation of other transport sectors such as aviation and marine but these markets were outside the scope of this project.

2.2 Green gas across the economy

Trucks are expected to provide a significant early source of demand for both biomethane and hydrogen in the early stages of deployment as production of these gases ramps up. This is largely due to the cost of the incumbent fuel, diesel, being comparatively more expensive than energy sources used in other sectors of the economy such as natural gas supplied via the gas network or electricity supplied via the electricity grid. However, as production grows and costs fall, both biomethane and hydrogen could play a significant role in delivering early decarbonisation of other 'hard to decarbonise' sectors and provide a domestic source of zero-carbon energy into the long term.

Over 700,000 business and residential properties are currently supplied by the gas network in ROI and this demand accounts for roughly two fifths of gas demand in Ireland. If production capacity is ramped up rapidly over the next 10-15 years biomethane could support decarbonisation of trucks and heating in buildings, providing a decarbonisation option before zero-emission technologies relying on electrification or hydrogen can be deployed at scale.

As a drop-in replacement, biomethane injected into the gas network would directly displace the use of fossil natural gas. A key benefit of this is that consumers would not notice any difference, allowing emissions in Ireland to fall without requiring costly changes to equipment or the building fabric. Biomethane can therefore begin to achieve decarbonisation of heat early on, while other necessary activities such as improving the thermal efficiency of buildings can take place to allow the rollout of more efficient systems. In the long term, as demand for gas from trucks falls, there will be significant volumes of biomethane available to decarbonise the heating of buildings that would otherwise be hard to decarbonise through electrified heating.

In the short term, as early green hydrogen projects take off in Ireland, they will need to be coupled with end users, principally in transport, where the hydrogen can be delivered directly via tube trailers. As production ramps up in the 2030s, hydrogen can begin to be delivered at scale as a blend with natural gas on the gas network. This will help to decarbonise gas use across the economy as increasing proportions are injected into the network, up to a maximum of 20% by volume. Beyond this point, end-user appliances would need to be changed and so converting the gas network to supplying 100% hydrogen would be beneficial at this stage to facilitate greater volumes of green hydrogen production. Hydrogen will then have a long-term role in Ireland to decarbonise heating and provide zero carbon energy for users across the economy that are currently dependent on fossil natural gas.

3 Biomethane production potential

Given its large agricultural sector, ROI produces significant quantities of biomass and farm waste feedstocks that are suitable for use in anaerobic digestion (AD) plants to produce biomethane. However, being a more sparsely populated island with less industry than GB, ROI has less feedstock that is suitable for producing Bio-SNG via gasification. This section sets out the range of potential volumes of biomethane and Bio-SNG that ROI could produce domestically out to 2050.

3.1 Biomethane from Anaerobic Digesters

Anaerobic digesters (AD) are an established technology that is already being deployed at scale in many European countries to turn a range of biomass feedstocks into biogas. Biogas is a mixture of methane and carbon dioxide which can be burned directly to produce heat, or generate electricity, or upgraded to biomethane by removing the carbon dioxide before injection into the gas network. For simplicity, the term 'biomethane' is used in this report for all methane produced via anaerobic digestion, while 'Bio-SNG' is used for methane produced through gasification (see following section).

It is challenging to estimate the quantity of biomethane that could be produced from AD plants in ROI, as the feedstock resource is dispersed on farms across the country and the volume that can be economically processed into biomethane will depend on the policies that are put in place to support it. Some estimates have put the total theoretical biomethane feedstock resource in ROI from the main agricultural sources of cattle slurry and grass silage as high as 138 PJ[8] (38TWh or 72% of the total primary supply of natural gas in ROI in 2020). However, the same report identifies that without significant increases in policy support, the amount of this theoretical resource that could economically be turned into biomethane is just 1-3.4TWh, demonstrating that while the potential is high, a range of factors will determine how much of this can practically be utilised in ROI.

Grass silage is the largest single feedstock resource for AD plants in ROI, with roughly 60% of all land in ROI designated as grassland[9]. Grass is currently grown as animal feed and either harvested as silage for use in the winter months or grazed directly from the fields. To ensure that grass used as a feedstock for AD plants does not compete with grass for livestock, additional production is required beyond the needs of Ireland's herds.

KPMG report that an additional 3.1 million tonnes of dry mass (m tnDM) of grass could be produced in ROI via improved efficiency (a 10% increase over current grass production) and used as a feedstock without impacting on the quantity available for livestock. Research conducted as part of the Heartlands Project[10] has shown that significant increases in grass production can be achieved by increasing the variety of grasses planted and improving the fertility of the soil. These practices applied together have been shown to increase grass production from 6 to 12 tonnes dry mass per hectare (tnDM/ha), while reducing the requirement for chemical nitrogen fertilisers.

Biomethane produced in ROI will also need to meet the increasingly stringent sustainability criteria set out by the EU's RED II, which will require AD plants starting operation from 2026 to achieve an 80% GHG saving. Grass as a feedstock alone will not meet this requirement and will need to be co-digested with animal slurry. The inclusion of slurry lowers the overall

[8] O'Shea et al., 2017, Assessing the total theoretical, and financially viable, resource of biomethane for injection to a natural gas network in a region
[9] CSO, 2020, Land use indicators Ireland, Land Use - CSO - Central Statistics Office
[10] Heartland project, 2021, Sward Performance — Heartland (heartlandproject.eu)

emissions for biomethane by capturing methane which would otherwise be released directly to the environment when slurry is spread on fields as fertiliser. In addition, the digestate produced as a by-product from AD plants can be used in the production of biological fertilisers, displacing chemical nitrogen fertilisers which produce GHG emissions during production[11].

KPMG estimate that ultimately 9.5TWh of biomethane could be produced sustainably in ROI from on-farm feedstocks without negatively affecting biodiversity or intensifying farming in sensitive areas. This is in the same region as the 11.7TWh identified in the SEAI's 'All AD feedstocks' scenario[12], as well as their assessment that 10.4TWh of silage and slurry feedstocks could be available for biomethane production by 2035[13]. This is also well within the total theoretical quantity of biomethane from grass which has been estimated elsewhere as 35.6TWh[14] to 38.3TWh[15]. The amount of slurry required for co-digestion with this quantity of grass would be 6.65 wet tonnes, roughly 15% of the slurry currently captured in ROI, and is broadly in line with the quantity of slurry that the SEAI has projected will be available for use as a feedstock by 2035[16].

Taking this into account, 9.5TWh is taken to be the total quantity of biomethane that ROI could economically produce each year once the industry is fully established. By comparison, the GB report identified 52TWh of biomethane potential. This equates to 0.8 TWh of biomethane from AD per million of population in GB and 1.9 in ROI. Considering that the agriculture sector in ROI makes up about 1% of GDP, which is roughly double the proportion of that of GB, this is broadly consistent with the GB report and appears to be a reliable estimate.

3.2 Bio-SNG from Gasification

A potential further source of biomethane is from the gasification of other biomass feedstocks that are not suitable for processing in AD plants. Gasification involves heating biomass to a high temperature in a low oxygen environment, producing syngas which is a mixture of methane, hydrogen and carbon monoxide gases. Through an additional methanation step, this gas can be purified to biomethane, with steam and hydrogen produced as by-products[17]. The process can also be adjusted to produce hydrogen as the main output, making this a potential long-term option for producing hydrogen from biomass. In this report, biomethane produced from gasification is referred to as Bio-SNG.

While gasification technology is still at an early stage of development, this could become an important option in the future to utilise wastes such as forestry residues, waste wood and municipal solid waste (MSW). Goggins et al 2016[18] identified 3.2TWh of Bio-SNG production potential in ROI from a range of feedstocks, principally MSW, and forestry residues. An additional 1TWh from other waste wood and sawmill residues is identified by the SEAI[19] bringing the potential for Bio-SNG production in ROI to 4.2TWh. Energy crops could be the largest single source of feedstock for Bio-SNG plants in ROI, representing an estimated

[11] KPMG, 2021, Sustainability of Biomethane Production in Ireland, [biomethane-sustainability-report-2021.pdf (gasnetworks.ie)](biomethane-sustainability-report-2021.pdf)
[12] SEAI, 2017a, Assessment of Cost and Benefits of Biogas and Biomethane in Ireland
[13] SEAI, 2017b, Bioenergy Supply in Ireland 2015 - 2035
[14] Ceileachair, D et al., 2021, University College Cork, Alternative energy management strategies for large industry in non-gas-grid regions using on-farm biomethane
[15] O'Shea, R, et al., 2017, Assessing the total theoretical, and financially viable, resource of biomethane for injection to a natural gas network in a region
[16] SEAI, 2017b, Bioenergy Supply in Ireland 2015 - 2035
[17] ETIP Bioenergy, 2020, Bioenergy Fact Sheet
[18] Goggins, J. et al, 2016, Resource Assessment for Bio-SNG Production via a Nationwide System of Gasification and Methanation in Ireland
[19] SEAI, 2017b, Bioenergy Supply in Ireland 2015 - 2035

3.6TWh of gas production[20]. However, as the land required to grow this quantity of additional crops would compete with the land required above for grass silage production, the potential of this feedstock is excluded in this report. As a result, this estimate of Bio-SNG production potential in ROI is considered to be conservative.

3.3 Production ramp-up and transport

Figure 2 shows how the total production of biomethane and Bio-SNG could be ramped up according to an ambitious timeline that would allow ROI to take advantage of its domestic feedstock availability and accelerate decarbonisation in the short term. This ramp-up rate assumes that ROI doubles its target for biomethane production from agricultural feedstocks to 3.2TWh by 2030 compared to the target set out in the 2021 Climate Action Plan. This would be in line with the recent doubling of the EU's target for biomethane production across the bloc in response to Russia's invasion of Ukraine[21]. This quantity of gas production is also broadly in line with the volumes envisaged by Project Clover[22], which aims to deploy 125 AD plants on Irish farms by 2030, which would be capable of producing 2.5TWh per year.

With a concerted effort to deploy Bio-SNG production capacity in ROI, an additional 0.8TWh could be available by 2030, equivalent to the production potential of one large scale gasification plant. This would bring the total biomethane capacity in Ireland to ~4TWh by 2030. With a rollout of biomethane production capacity at this rate, all projected demand from gas trucks in 2030 (2.4TWh) could be met with domestically produced biomethane. Even if this scale of gas truck deployment were achieved, there would be sufficient remaining biomethane injected into the grid to contribute over 30% of the 'higher ambition' target set out in the RHO consultation[23].

This should be an achievable ramp-up rate for the production of biomethane in Ireland. It is a slower rate than discussed in the GB report, which envisages over 60% of the biomethane production potential to be deployed by 2030. The faster rate in GB reflects both the fact that the AD biomethane industry is more advanced currently, but also that there is a much shorter window of opportunity for this industry, before the gas system switches to focus on 100% hydrogen. In ROI there could be a longer-term role for the direct use of biomethane but increasing the supply of biomethane is still time critical. Climate change is a problem today and decarbonisation options needed to be deployed as quickly as possible. Also, alternatives to gas-consuming technologies, such as heat pumps coupled with renewable electricity generation are gathering pace and costs are falling rapidly. To ensure that biomethane can fulfil its potential role in decarbonisation, getting to scale by 2030 will be essential if the biomethane industry is to avoid being superseded by alternatives. Therefore, exceeding the ramp-up rate presented here should be a key objective of the gas industry in the coming years.

[20] Goggins, J. et al, 2016, Resource Assessment for Bio-SNG Production via a Nationwide System of Gasification and Methanation in Ireland
[21] European Commission, 2022, Factsheet - REPowerEU (europa.eu)
[22] KPMG, 2021, Project Clover KPMG Feasibility Summary Nov 2021 (renewablegasforum.com)
[23] Irish Government, 2021, gov.ie - Consultation on the Introduction of a Renewable Heat Obligation (www.gov.ie)

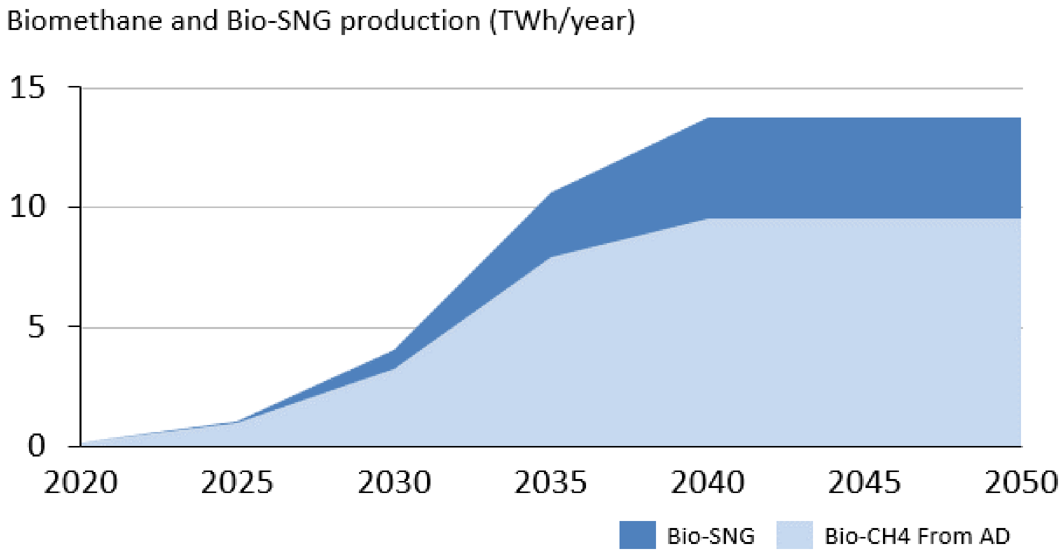

Figure 2 – Biomethane and Bio-SNG production potential in ROI

The gas network in ROI will be essential for transporting this quantity of gas from producers to consumers. AD production is expected to take place mostly at small scale plants (20-40GWh/year) located on farms close to the source of feedstocks and be transported to the network via a virtual pipeline, with gas trucked in compressed gas tankers to centralised grid injection (CGI) facilities. One such CGI facility has already been constructed at Cush (36GWh/year capacity), with a second in progress at Mitchelstown (700GWh/year capacity). The larger site is capable of injecting biomethane from more than 20 AD plants and roughly 14 sites such sites would be required to inject the 9.5TWh of biomethane from AD projected above.

GNI expect that trucks delivering gas to a CGI from up to 50kms away will be economically viable and given the small geographical size of ROI, the 14 CGI sites would provide access to the gas network for farms across the country. This is consistent with analysis from the University of Cork that 70% of the biomethane resource is within 15kms of the gas network[24], suggesting that tube trailer deliveries of gas from producers to injection sites would not present significant operational challenges.

Gasification plants can be built at different scales, depending on the availability of feedstocks. It may be advantageous to locate large-scale plants that process MSW at or near to locations where MSW is already routinely collected. These sites would then require their own grid injection facilities to supply the gas via the network. In other cases, smaller plants processing feedstocks that are more dispersed such as forestry residues may be preferable, which would require tube trailer deliveries to CGI sites.

[24] Ceileachair, D et al., 2021, University College Cork, Alternative energy management strategies for large industry in non-gas-grid regions using on-farm biomethane

4 Green hydrogen production

Green hydrogen production depends on renewable electricity generation to supply electrolysers which use it to split water into its components of hydrogen and oxygen. This section sets out the scale of the green hydrogen production potential in ROI by examining the quantity of renewable electricity that could be generated in the country over the next 30 years. As renewable electricity generating capacity is added there is a greater potential for curtailment during times when electricity supply from intermittent renewables outstrips demand and green hydrogen production is one potential option for flexibly using this excess electricity.

4.1 Increasing renewable electricity generation capacity

The Irish government plans to increase the share of renewable electricity generated in the country to 80% by 2030 according to the National Development Plan 2021-2030[25]. To achieve this, the government aims to hold auctions under the Regular Renewable Electricity Support Scheme (RESS) to deliver up to 2.5GW of solar, 8GW of onshore wind and 5GW of offshore wind. To provide dispatchable power when wind and solar generation is insufficient, an additional 2GW of gas generation capacity is also planned.

With all this additional and mostly non-dispatchable generating capacity on the Irish grid, there is expected to be a significant need for energy storage and demand side management to match demand with supply across the year[26]. This could create a major opportunity to use excess electricity generation to produce green hydrogen through electrolysis, which can then be stored and distributed through the gas network when energy demand increases.

EirGrid's 2019 Tomorrow's Energy Scenarios (TES) report, provides a useful basis for estimating the amount of excess electricity that could be produced in ROI. Figure 3 shows the generating capacity in the 'Coordinated Action' scenario, however despite being the TES scenario that leads to the greatest penetration if intermittent renewables, the capacity set out in this scenario would not meet the new NDP target for 2030. The additional capacity necessary to meet this target has been added, assuming that the targets of the NDP will be

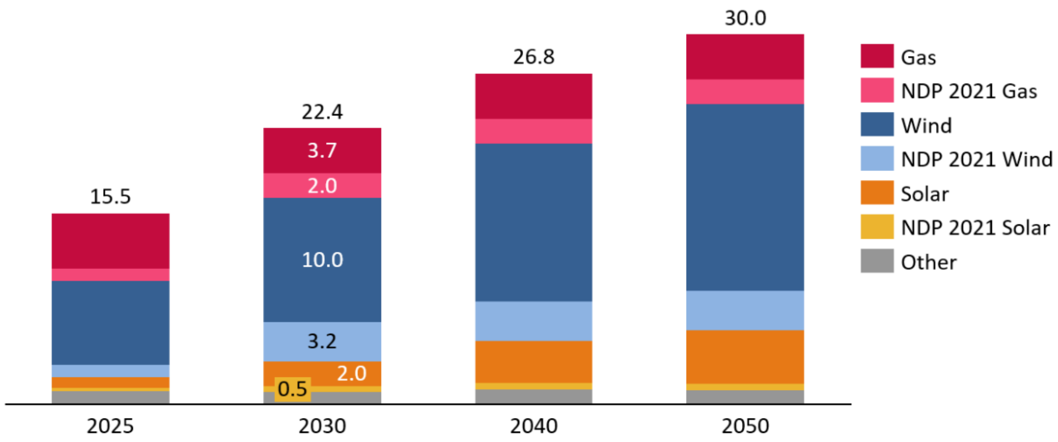

Figure 3 - Generating capacity based on EirGrid's Coordinated Action, with additional gas, wind and solar capacity added to meet the capacity levels set out in the NDP 2021-30 (GW)

[25] Irish Government, 2021, National Development Plan 2021-2030
[26] EirGrid, 2019, Tomorrow's Energy Scenarios

met. Achieving an electricity system with this high level of intermittent renewable generating capacity (wind and solar) suggests that the capacity factors of all generating assets is likely to fall over time. This is due to the amount of electricity that is likely to be dispatched down due to constraints on the Irish electricity grid as set out in a recent study for the SEAI[27]. That study found that without measures such as large scale green hydrogen production, curtailment of renewable electricity generation could reach 45% by 2040.

Figure 4 provides an estimate of the additional electricity which could be generated with the installed capacity shown in Figure 3 if grid constraints and curtailment were not an issue. This level of electricity generation could be possible, for example, if large-scale electrolysers were in place and ready to use any electricity generation that would otherwise be curtailed. The quantity of electricity shown in each year has been calculated assuming that gas plants are able to continue generating at their current capacity factors[28], wind generation capacity factors increase at their full technical potential[29] and solar generators continue to generate at their current capacity factors experienced in the region[30]. The red line in Figure 4 shows the electricity demand projected in the Coordinated Action scenario, demonstrating that a large quantity of excess electricity could be used to produce green hydrogen.

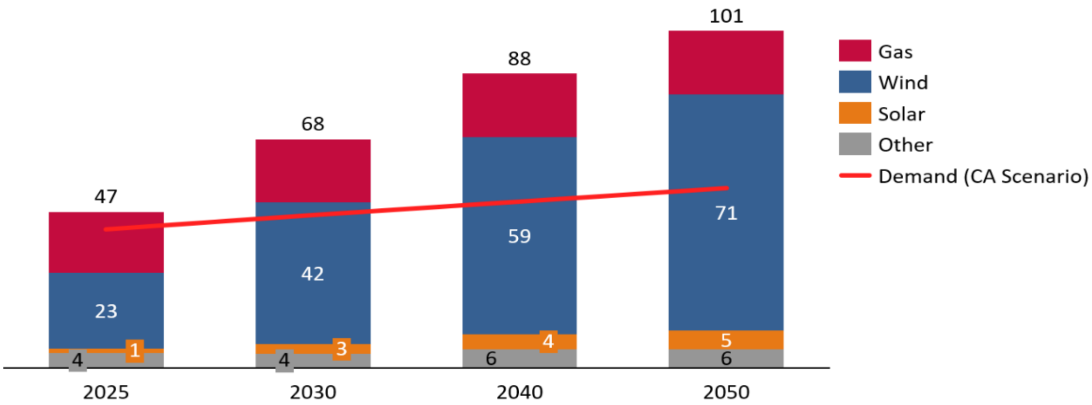

Figure 4 - Electricity generation possible in Ireland (with the generating capacity shown in Figure 3, compared to projected electricity demand under EirGrid's Coordinated Action scenario (TWh)

4.2 Green hydrogen production potential

Figure 5, shows that up to 35.7TWh per year of green hydrogen could be produced in ROI by 2050 if all the excess electricity identified in the previous section were utilised for this purpose. The slow ramp-up in the early years reflects the fact that large-scale electrolysers are still at the development and early deployment stage, but from 2030 green hydrogen production in Irealnd could ramp up quickly.

Before 2030, smaller green hydrogen projects will need to be developed in ROI to support the early deployment of hydrogen vehicles and establish skills and capabilities within ROI for a hydrogen supply chain. The currently high capex costs of electrolysers means that projects deployed over the next decade are likely to require high capacity factors to be

[27] Blount, P. et al, 2020, Identifying the relative and combined impact and importance of a range of curtailment mitigation options on high RES-E systems in 2030 & 2040
[28] Calculated at 38% based on existing gas generation capacity and electricity production
[29] EirGrid, 2019, Tomorrow's Energy Scenarios, p.47
[30] EirGrid & SONI, 2021, Annual Renewable Energy Constraint and Curtailment Report 2020, p.29

economically viable. As a result, they will most likely need to be grid-connected to guarentee high run times and will therefore have little flexibility to absorb curtailed electricity generation.

Electrolyser manufacturers such as ITM Power are scaling up production volumes as well as the size of individual electrolyser units with the aim of rapidly reducing capex costs over the next decade. By 2030, if projected electrolyser capex cost reductions from £1,500/kWe in 2021 to £600/kWe can be achieved, projects with capacity factors as low as 36% could be envisaged[31]. By more than halving capex costs from today's levels, plants could be oversized to maximise production during the times when electricity is abundant and cheap and then switch off when supply and demand are balanced and prices rise. Such projects could begin to be deployed in ROI from 2030, reaching full scale by 2050. They could then take advantage of the excess electricity generated by the ambitious levels of intermittent renewable generation set out in the previous section.

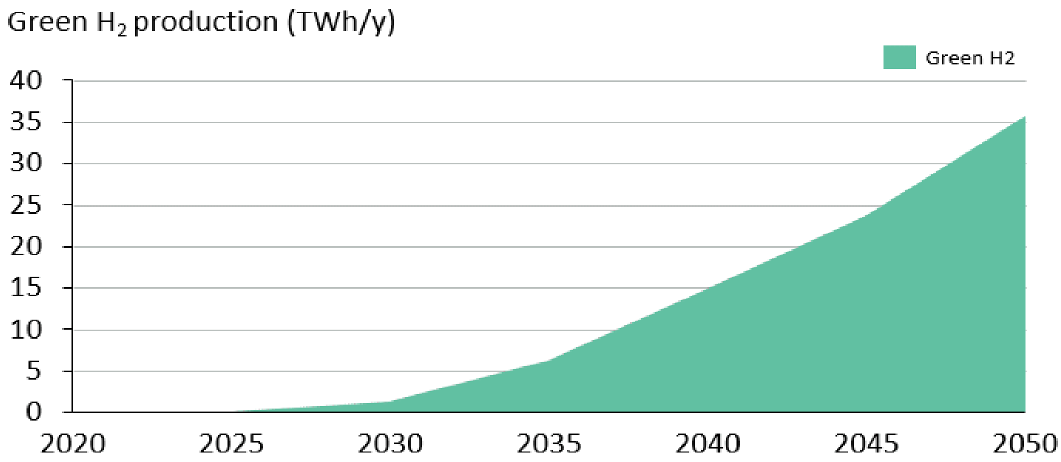

Figure 5 – Possible range of green hydrogen that could be produced from excess electricity generation in Ireland

Green hydrogen production is currently considered to be the only route for domestic hydrogen production in ROI. Blue hydrogen, produced through reformation of natural gas with the resulting carbon by-products captured and stored, is not considered a viable option due to the limited domestic fossil natural gas resources and limited domestic opportunities for carbon storage. However, if ROI were not able to achieve the level of green hydrogen production set out in Figure 5, it is possible that additional supplies of hydrogen could be delivered onto the network via the exitsing GB interconnector.

GB's GDNOs expect a low (5%) blend of hydrogen on the network around the Moffat entry point from 2035[32], growing to 20% by 2040, before transitioning to pure hydrogen in the 2040s. The GB interconnector supplied roughly 40TWh of natural gas to ROI in 2020 and gas pipelines are expected to have 80% of the capacity, by energy, when transporting pure hydrogen compared to natural gas[33]. This would be equivalent to 32TWh of hydrogen that could be delivered to ROI through the GB interconnector, providing security of supply if domestic production is lower than anticipated. The total capacity of the interconnector is significantly higher at roughly 140TWh of natural gas per year, providing flexibility for peak periods. Conversely, while the GB interconnector is currnetly a one-way system, if excess hydrogen could be produced in ROI, the interconnector could be converted to allow export of hydrogen to GB.

[31] BEIS, 2021, Gigastack Phase 2: Pioneering UK renewable Hydrogen
[32] Element Energy, 2021, The Future Role of Gas in Transport
[33] ACER, 2021, Transporting Pure Hydrogen by Repurposing Existing Gas Infrastructure: Overview of existing studies and reflections on the conditions for repurposing

5 The role of the gas network in ROI

This section brings together the green gas production potential for ROI identified in the previous two chapters and explores the implications for the gas network.

5.1 The mix of green gases in ROI to 2050

For the gas network to remain a valuable asset in ROI, the gases it transports must be decarbonised over time. Figure 6 shows how the mix of gases supplied by the Irish gas network could change over the next thirty years if the green gas production potential identified in the previous two chapters is realised. The total quantity of gas supply shown is taken from GNI's Vision 2050 report, with any shortfall between this total and the potential for green gas supply coming from fossil natural gas until 2045. Beyond this point any shortfall in domestic supply of green gases could be made up with hydrogen imports via the GB interconnector.

As this chart shows, the green gas with the best technology readiness level is biomethane and so this must ramp up first to deliver early emission savings. This is a drop-in fuel so can be blended at any rate with natural gas without impacting end users. Biomethane is likely to be the dominant green gas produced in ROI until 2040. However, even with a rapid rollout in the early years, there is insufficient biomethane production potential to meet Ireland's gas demand and so green hydrogen production must be rapidly expanded from 2030 to further displace natural gas consumption.

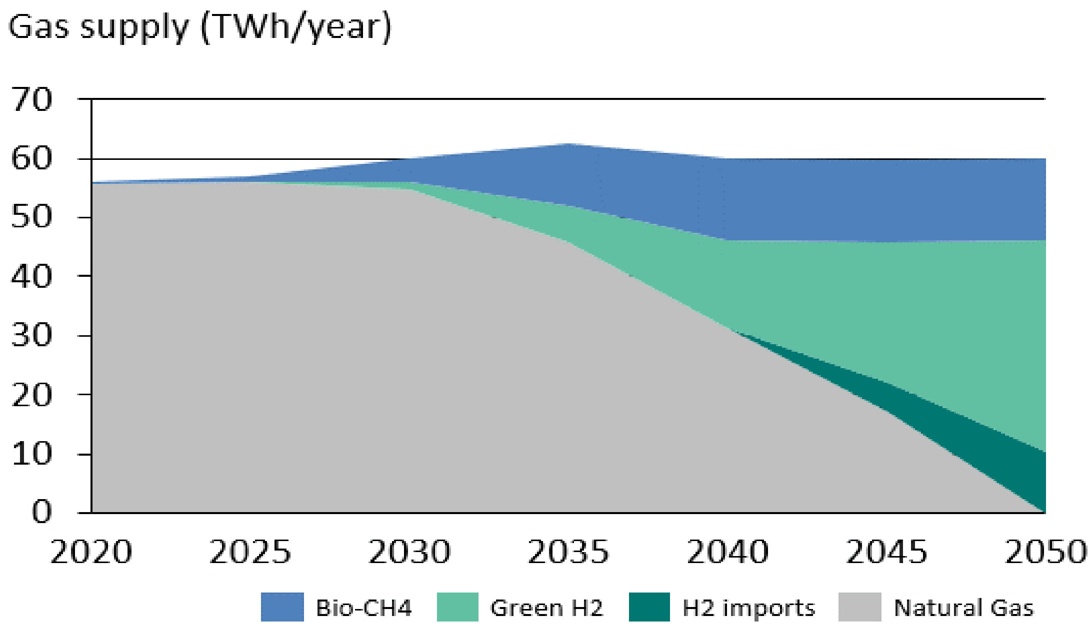

Figure 6 – Projected mix of gases supplied by the Irish gas network 2020-2050

By 2050 ROI could supply up to 83% of gas demand with the domestically produced green gases identified in this report. This is a major improvement from today, where over half of Ireland's gas is imported from GB and ROI is expected to be dependent on imports for 90% of its gas needs by 2030 as the Corrib gas field is depleted[34]. If the total quantity of gas required in ROI by 2050 follows the level set out in GNI's Vision 2050 report, then ROI will continue to require some imports of hydrogen, equivalent to at least 10TWh per year.

[34] Irish Government, Policy Information – Gas, 2021, gov.ie - Gas (www.gov.ie)

However, over half of ROI's gas is currently used for electricity generation and it is likely that this demand will fall between now and 2050 as electricity generation increasingly comes from the non-dispatchable sources as set out in Chapter 4. In addition, electrification may prove to be a more effective route for decarbonising some current uses of gas for heating or industrial purposes. If the total gas required by 2050 is lower than currently projected, then it is possible that ROI could supply all its gas demand with domestically produced green gases.

5.2 Implications for the role of the Irish gas network

In the GB study, the gas network was expected to transition completely to supplying 100% hydrogen by 2050 leading to a decline in the quantity of biomethane produced during the 2040s. This is due to hydrogen making up over 80% of the identified green gas production potential in GB. As a result, there was a clear benefit to transitioning to a hydrogen-only network, leaving only a limited number of biomethane producers and consumers relying on a dedicated pipeline or tube trailer delivery of the gas. Biomethane and Bio-SNG represent roughly 30% of the green gas potential in ROI, a larger proportion than in GB, which suggests there could be a greater long-term role for the direct use of these gases, but this would require continued transport of biomethane and hydrogen on the gas network.

The mix of biomethane from AD and Bio-SNG is also different in GB and ROI. In GB, biomethane from AD feedstocks represent just 40% of the total, while in ROI the proportion is 70%. As discussed in Chapter 3, on-farm feedstocks for AD are dispersed across the country and will be dependent on local CGI facilities to inject the biomethane produced into the network to be transported to customers. Bio-SNG plants are more likely to be large-scale and make use of waste feedstocks such as MSW that are already routinely collected and brought to a centralised location. They will be less dependent on the gas network than AD plants, if suitable large-scale consumers can be identified nearby.

This highlights the long-term role the Irish gas network will continue to play in transporting biomethane and Bio-SNG, even as hydrogen production ramps up across the country. Instead of a dedicated hydrogen network as is expected to be the case in GB, biomethane and hydrogen will need to co-exist on a mixed Irish gas network in order to maximise the decarbonisation potential of these green gases.

The existing structure of the gas network in ROI suggests one way that this co-existence could be possible. As shown in Figure 7, the Irish gas transmission network is made up of a 'main ring' of pipelines that run in a loop around much of the ROI, with 'spurs' connected to this ring serving individual regions, towns or cities. It is possible that each spur could supply a different mix of gases depending on the type of gas that is produced locally and the requirements of local users. Since there is roughly two and a half times as much potential for green hydrogen production potential than biomethane, it is likely that the main ring would eventually transition to 100% hydrogen, while individual spurs would supply varying mixtures of hydrogen and biomethane. In this way, the gas network could facilitate the full deployment of Ireland's green gas potential.

Figure 7 - Transmission network in the Republic of Ireland

6 Conclusions

This study has found that many of the conclusions of the GB-focused report apply in ROI. Both countries have substantial potential to produce green gases domestically and there is a significant opportunity to leverage the potential of gas-powered trucks to support the growth of this industry early on. In the short term, biomethane use in heavy trucks will deliver emissions reductions while alternatives remain unavailable. Later, as hydrogen trucks become commercially available, they can provide an early source of demand to help establish this industry, achieve scale and bring down costs so that hydrogen can be deployed widely across the economy to deliver long-term decarbonisation.

The key differences between the GB and ROI cases are driven by the mix of green gases that each country has the potential to produce. In ROI, biomethane makes up a greater proportion of the green gas potential than in GB. This is in part due to the significant feedstocks for AD plants that could be produced by Ireland's agricultural sector which makes up a larger part of the economy than in GB. It is also due to GB's domestic natural gas resource and CCS opportunities, which mean that blue hydrogen production is expected to be produced at scale alongside green hydrogen. In Ireland hydrogen production will be limited to the quantity of green hydrogen that can be produced from renewable electricity generation.

The greater role of biomethane in ROI leads to other differences between the two countries. In GB, the direct use of biomethane in transport and heating peaks in 2040, after which it has a reduced long-term role in displacing fossil natural gas use at large scale facilities that are fitted with CCS technology. This is then able to deliver negative emissions and offset continued emissions in other sectors. In ROI, the greater potential for biomethane in the mix of green gases, and the lack of domestic opportunities for carbon storage, suggests that its direct use as a low-carbon energy source is likely to continue after the peak of demand from gas trucks passes in the mid-2030s. After this point, significant volumes of biomethane will be available to support decarbonisation of all gas users connected to the network.

These differences have a knock-on impact on the role of the gas network itself in ROI. Long term, the GB gas network is expected to complete a transition to supplying 100% hydrogen during the 2040s. However, in Ireland, the more balanced mix of biomethane and hydrogen potential suggests that the gas network will continue to have a role in transporting both these gases in the long term. This report has identified two and a half times as much green hydrogen as biomethane production potential, so some sections of the Irish gas network will likely need to transition to 100% hydrogen. The mix of gases supplied on other sections of the network will then be determined by local production potential and the requirements of local users.

7 Appendix

7.1 Narrative Summary - Green Gases in ROI to 2050

The table below summarises the narrative for green gases in ROI out to 2050 and the main developments that would need to take place in each 5-year period to achieve the full potential of green gases in ROI. The first two columns show how the production of green gases would grow over the period and how they would be transported to end users, either via the gas network or tube trailer deliveries. Alongside this, the next two columns show who would be the main consumers of the gases and the role these gases would play in decarbonisation across the economy. The final column shows the timeline for the deployment of gas truck refuelling infrastructure, starting with a ramp up to support vehicles running on natural gas and later converting to supply hydrogen to trucks and other vehicles in the fleet.

Table 1: Overview of the decarbonisation narrative for ROI

Year	Fuel	Production	Transportation	Consumption – Economy wide	Consumption - Trucks	Truck Refuelling Station
2020-2025	Bio-CH_4	Increased ambition and policy support from the government accelerates deployment rates for biomethane production from AD, starting with low-cost waste feedstocks at sites closest to the gas network for injection	Gas grid	Early production injected into the grid to support the decarbonisation of gas users in heat and industry. Domestic use for heat increases as more homes connect to the grid and oil use declines	Rapid rise in gas truck sales	Rapid rollout of public and depot stations spread across the whole of ROI
	H_2	Government or European funded large-scale trial of green H2 from electrolysis. Early electrolysers are expensive meaning electrolysers located at wind farms will still need a grid connection to run when the windfarm output is low	H2 trucked in compressed tube trailers to refuelling stations from production sites	Early projects focus on transport applications where diesel costs are high and low volume hydrogen can best compete	Large commercial demonstration of 100 medium duty H2 trucks. This helps to provide a high value anchor load for early H2 projects	Small stations (0.5t/day) installed at strategic locations for depot clusters

Year	Fuel	Production	Transportation	Consumption – Economy wide	Consumption - Trucks	Truck Refuelling Station
2025-2030	Bio-CH_4	Sustained supportive policies mean that the ramp up rate for on-farm production of biomethane production from grass silage accelerates, with farms further from the network upgrading to biomethane on-site and trucking to centralised grid injection facilities. New Bio-SNG production from collected wastes such as MSW begins near to Dublin by 2030	Gas grid with low levels of H2 blending in trials	Substantial quantities of biomethane are supplied to the gas network, helping to achieve early decarbonisation across heat and industry while capacity and know-how for switching to hydrogen long term is built up	Gas truck sales peak	National coverage with ~20 high capacity public stations. No new station built after 2030
	H_2	Early project to use wind farm plus grid electricity to guarantee supply and reduce H2 costs. As scale ramps up, excess H2 production is injected into the grid to support decarbonisation of heat	H2 trucked in compressed tube trailers to stations from production sites. Some excess H2 from early projects injected to grid	Mostly focusing on transport where diesel costs are high and low volume hydrogen can best compete. Additional hydrogen produced as projects scale up is injected into the gas network to support decarbonisation of heat, industry and power	H2 truck sales accelerate in medium duty applications facilitating deployment of larger H2 production projects	More stations (Up to 1t/day) added to support clusters of depots and to begin national coverage along motorways, possibly co-located with the last generation of CNG/LNG stations built where there is sufficient footprint at the site

Year	Fuel	Production	Transportation	Consumption – Economy wide	Consumption - Trucks	Truck Refuelling Station
2030-2035	Bio-CH_4	Full utilisation of biomethane feedstocks that can be economically delivered to centralised grid injection facilities. Utilisation of Bio-SNG feedstocks continues to grow, primarily from wastes collected in large towns and cities	Gas grid with H2 blending increasing to the 20% blending limit in key regions of the grid	Biomethane and bio-SNG used extensively in heat and industry as it takes a significant share of the mix in the gas grid	Gas truck stock peaks and sales fall until they are limited to only the longest-range trucks	Early stations start to need equipment overhaul. Sites start to gradually increase share of H2 dispensed alongside Bio-CH4 over time.
	H_2	Cost reductions in electrolysers allow a large growth in green H2 from electrolysers co-located with wind farms without a reliance on grid electricity for high run times. This allows green H2 to production to soak up an increasing share of the excess electricity generation from a system with high penetration of intermittent renewables	H2 trucked in compressed tube trailers to stations from production sites or fed directly by short pipeline from production sites. As supply grows and costs fall H2 increasingly injected to the grid, reaching 20% blend limit around major production areas	Small amounts of H2 used by heat and industry through blending in the gas grid although no equipment changeover is needed at this point. H2 demand in heavy duty transport begins rapid growth phase	H2 becomes the industry preferred fuel for long-haul applications, sales expand rapidly	Stations (up to 2t/day) added to support clusters and large depots. National coverage along motorways developed as H2 dispensing option added to CNG/ LNG stations

Year	Fuel	Production	Transportation	Consumption – Economy wide	Consumption - Trucks	Truck Refuelling Station
2035-2040	Bio-CH_4	Full utilisation of all biomethane feedstocks that are within 15km of the gas network and most bio-SNG feedstocks also utilised	Main ring of the gas network converts to 100% H2. Bio-CH4 sites close to converted sections of the grid truck their gas to injection at other points in the grid where a blend is still supported	Biomethane and bio-SNG used extensively in heat, industry and power. Biomethane on the network peaks as use of electrification and H2 for decarbonisation grows	Gas truck sales have ended, and the stock declines	Most stations need equipment overhaul and start 5-year conversion to H2 to buffer falling CNG demand
	H_2	Green H2 from electrolysis at large scale wind sites using predominantly curtailed electricity	Small stations continue to be supplied by H2 trucked in compressed tube trailers from production sites. Larger stations are fed by short pipeline from production sites or directly from the gas network in newly converted 100% H2 main ring of the gas network	H2 increasingly used by all sectors connected to the gas grid. Some regions begin to receive 100% hydrogen, requiring equipment to be changed. Other regions continue to receive a blend of H2 and CH4.	H2 truck sales grow and peak by 2040. H2 is now the dominant fuel for long-haul applications	Stations of all sizes (Up to 3t/day) added to support depot clusters, large depots and daughter depots. The backbone of infrastructure for trucks provides national coverage for other vehicle segments, allowing hydrogen to become a widely used transport fuel.

Year	Fuel	Production	Transportation	Consumption – Economy wide	Consumption - Trucks	Truck Refuelling Station
2040-2050	Bio-CH_4	Biomethane/bio-SNG produced near regions of the grid supporting a blend continues, while remote biomethane production near sections of the grid supplying only H2 begins to decline	Additional regions of gas grid convert to 100% H2. Many more biomethane producers now truck their gas further for grid injection, making some remote sites unviable	Biomethane/bio-SNG continues to supply heating, industry and power in areas with a blend on the grid	All gas trucks have left the stock	All stations complete their conversion to H2
	H_2	Green H2 from electrolysis at large scale wind sites using predominantly curtailed electricity	Small stations continue to be supplied by H2 trucked in compressed tube trailers from production sites. Larger stations are fed by short pipeline from production sites or from the expanded sections of converted gas grid	H2 continues to supply heating, industry and power in areas with a blend on the grid and areas with 100% H2 on the grid	H2 truck market maintains a constant share of sales, predominantly in the long-haul market (the rest is battery electric)	Stations of all sizes (up to 3t/day) added to support depot clusters, large depots, and daughter depots