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Renewable Hydrogen and End-users' Considerations for the Transition to a Renewable Gas Network (HyEnd)

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Abbreviations

CAP	Climate Action Plan published by the Government
CBP	Common Business Practice
CH4	Methane
CO2	Carbon Dioxide
CV	Calorific Value
DECC	Department of the Environment, Climate and Communications
DM	Daily Metered
EU	European Union
G2P	Gas to Power
GHG	Greenhouse Gas
H_2	Hydrogen
HyEnd	Hydrogen and End-users research project
HyTest	Testing of Hydrogen Blends in Gas Networks Ireland
LDM	Large Daily Metered
NCC	National Competitiveness Council
NDM	Non-Daily Metered
NI	Northern Ireland
NSAI	National Standard Authority of Ireland
OEM	Original Equipment Manufacturer
P2G	Power to Gas
ROI	Republic of Ireland
SEAI	Sustainable Energy Authority of Ireland
WI	Wobbe Index

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1 Introduction

The Irish Government recently set ambitious targets to increase production and usage of renewable gases in the 2023 Climate Action Plan (CAP). To support those renewable gas targets, the Department of the Environment, Climate and Communications published the "National Hydrogen Strategy" in July 2023, which emphasized the future role renewable hydrogen will play in decarbonising Ireland's state-owned gas network and the overall national energy system.

Generating renewable hydrogen by leveraging the huge potential of predominantly renewable wind energy and transporting through a modern well-developed gas network will offer several benefits, including the:

- **Reduction of carbon emissions**
- **High-level potential for energy storage**
- **Enhanced security of supply**
- **Creation of renewable electricity**
- **Potential for Ireland to become an energy exporter to Europe and global markets [1].**

To prepare the gas network for the onboarding of hydrogen into the system, Gas Networks Ireland has been undertaking a series of tests to examine the readiness of the network. In its Network Innovation Centre, the research and innovation teams have developed three distinct phases of projects in collaboration with various research institutes.

1 Phase One **(HyTest):**

Published in 2022, this project focused primarily on domestic appliances, which were tested with a variety of hydrogen blends to ensure the appliances could take up to 20% blending without any retrofitting requirement, and to ensure there was no impact on the cost in home settings [2].

The domestic appliances involved in the project included traditional gas fires, cookers, gas hobs, heating boilers, ovens, and gas wall heaters. These were tested in different stages measuring the energy value, monitoring, and measuring the emissions, leak and safety testing, domestic meter's accuracy, analysis of operational parameters such as pressure drop and flow rate, and flame picture.

2 Phase Two **(HyEnd):**

This research project, outlined in more detail throughout the report, focused on Large Daily Metered (LDM) and Daily Metered (DM) gas customers across Ireland to investigate their limits in using hydrogen blends. This research aims to address two key questions:

1. **What are the Large and Industrial Customers' equipment limits for hydrogen blends?**
2. **How will Ireland's gas network need to adapt to receive the renewable hydrogen to serve these customers?**

3 Phase Three **(HyGreenNet):**

This phase is currently ongoing with a focus on the distribution network, testing the medium and low operational pressure focusing on safety and leakage, material compatibility studies and detailing performance analysis of commercial package boilers.

1. Introduction

1.1 Hydrogen consumption pathways and the role of the gas network

Ireland's Climate Action Plan 2023 requires investment for storage and new technologies for system operation services to replace fossil fuels. Renewable hydrogen is expected to play a significant role in sector coupling and reducing the cost of decarbonisation across all industries. Moreover, flexible demand is expected to help offset fossil fuel production, enabling the utilisation of high-wind-speed sites offshore and onshore, particularly in power grid constrained areas.

These investments are essential to support a power system that can accommodate even more significant amounts of renewable energy from offshore wind. In the Irish Climate Action Plan 2023, there is a target to implement 2 GW of offshore wind capacity for renewable hydrogen by 2030. To achieve this, potential projects will involve an integrated net zero carbon energy system approach, including:

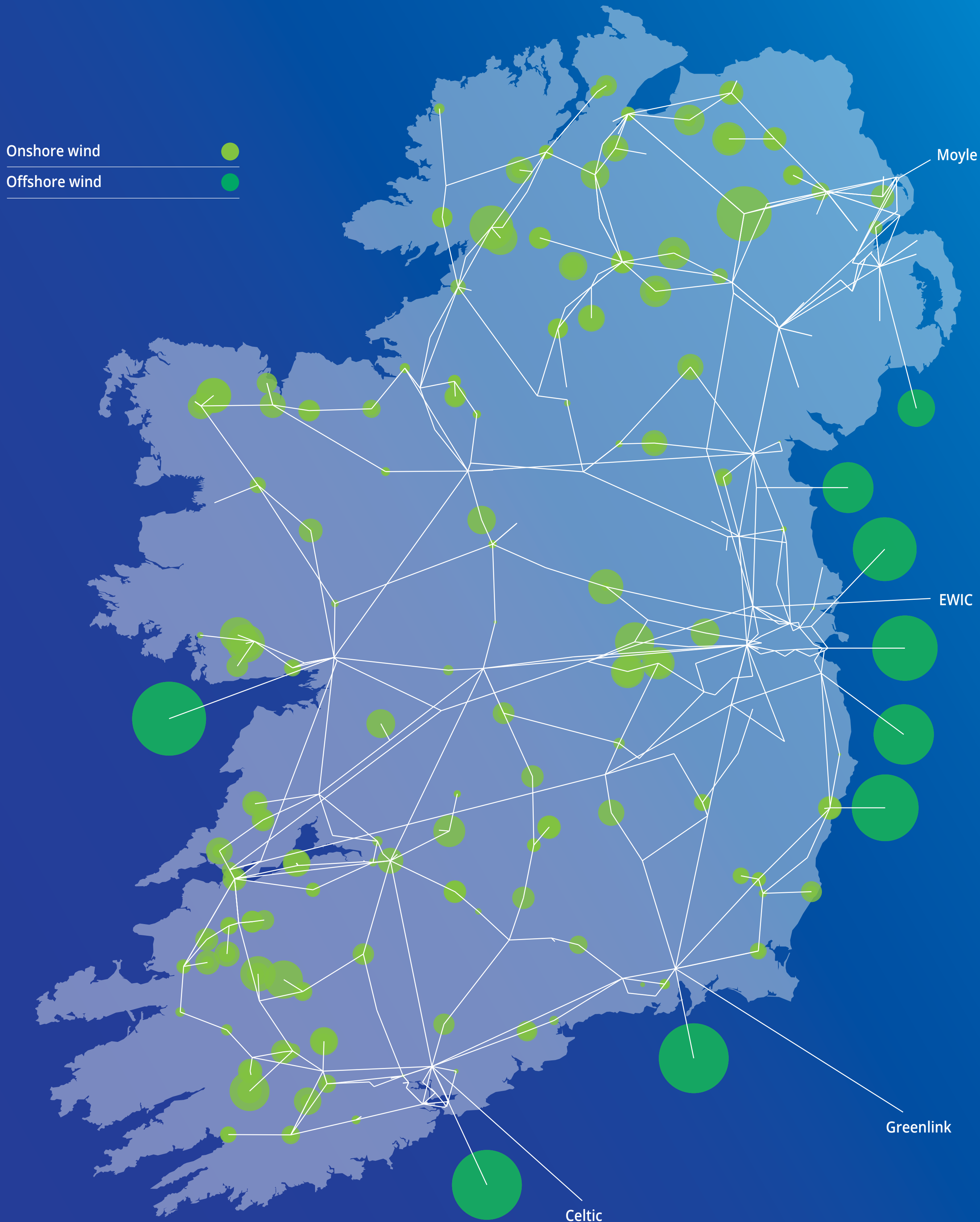
- Offshore wind generation to increase to 37 GW for primary energy.
- Renewable hydrogen production capability (>15 GW).
- Sub-sea salt caverns and depleted gas field storage for renewable hydrogen storage (up to 90 days).
- Dispatchable zero-carbon (renewable hydrogen) power generation (>10 GW) as a backup.

EirGrid has released an operation policy roadmap for the expansion of the electricity network from 2023 to 2030 [3]. They have also published the map shown in Figure (1), which displays the expected distribution of electricity generation by 2030. The map considers various sources of information, such as consultation feedback, grid connection applications, auction outcomes, and projections of available grid capacity, to determine the assumed locations for connecting renewable energy sources. These locations may change in the future, as new information becomes available and will be updated as part of future revisions of *Shaping Our Electricity Future.*

One of the technologies for hydrogen generation from renewable energy sources is power-to-gas (P2G) systems. Adding P2G systems, as a new interconnection, can increase the penetration of renewable power in the integrated energy system. To meet the CAP target and speed up the process of integration across energy networks (gas, water, and electricity grids), there will be a requirement for collaboration between Gas Networks Ireland and EirGrid alongside the Sustainable Energy Authority Ireland (SEAI), ESRI (Economic Social Research Institute), and CRU (Commission for Regulation of Utilities).

Gas Networks Ireland has previously completed studies to assess the technical feasibility of blending hydrogen into the gas network. These studies found that blends of up to 20% hydrogen can be safely and effectively used in the existing gas infrastructure without the need for major modifications. These trials have also shown that a 20% hydrogen blend can reduce carbon emissions by up to 8%, contributing significantly to meeting Ireland's climate targets.

Figure 1. Potential offshore wind farms in Ireland published by EirGrid [3]



1. Introduction

Table (1) outlines the shared characteristics and distinct differences between hydrogen and natural gas. These contrasting properties are particularly distinguishing, as they present challenges that need to be addressed to enable the widespread incorporation of hydrogen into the gas network.

Parameter	Natural Gas	Hydrogen
Relative Density (air=1)	0.55	0.07
Flammability limits (Mol %)	4.4 – 17	4.4 – 77
Ignition energy (mJ)	0.26	0.0017
Combustion energy (MJ/m^3)	38	13
Wobbe number (MJ/m^3)	48-54	41
Flame colour	Blue	Colourless
Molecular mass (g/mol)	16	2
Molecule size (pm)	220	75
Infrared absorption	Yes	No
Joule-Thompson coefficient (K/bar)	0.4	-0.03
Sound velocity (m/s)	338	1203

Table 1. General differences in properties between hydrogen and natural gas

2 Methodology

The initial step to achieve the project objective involved categorising and segmenting all customers of the Irish gas network into five groups:

1. **Power plants**
2. **Industrial units**
3. **Commercial units**
4. **Transport sector**
5. **Residential sector**

Subsequently, a questionnaire was created to survey Industrial and Commercial customers to investigate threshold levels for the consumption of hydrogen blends. The survey involved 42 LDM end users (seven gas-fired power plants and 35 large industrial units) and 270 DM end users across the country.

Equipment compatibility

The qualitative analysis highlighted that the industrial units required no significant modification to take a 20% hydrogen blend from the gas network. Furthermore, it showed that equipment compatible with hydrogen blends are already in use in industrial settings. Such examples included gas boilers for heating and drying processes and reciprocating engines in Combined Heat Power (CHP) plants.

Gas quality

Using the Wobbe Index (WI), the gas quality analysis highlighted the differences in gas quality[3] measured. The WI was selected as part of the methodology as it holds significant importance for gas-based fuel equipment because it directly affects the thermal input of most end-use equipment.

For context, looking at the two origins of Ireland's gas supply, the WI of natural gas in the Corrib Gas Field in Mayo has an average value of 47.3 MJ/m^3, and the WI in Moffat, Scotland is 48 MJ/m^3. On assessing the data obtained from surveying Gas Networks Ireland customers, it has been noted that the minimum WI required for their units is approximately 47 MJ/m^3. According to the energy analysis work package of the HyTest project, the minimum WI of a 20% hydrogen blend with natural gas is 47.6 MJ/m^3. This score remains within the thresholds (47.2-51.4 MJ/m^3) of published Common Business Practice (CBP) by EASEE for WI, guidelines designed to simplify and streamline business processes between stakeholders [2].

Gas-fuelled devices have varying degrees of acceptance of hydrogen blend levels. Some devices require customer equipment modifications to use hydrogen, while others do not. The allowable limit for hydrogen has been determined through standard practical projects, establishing operating limitations like the Wobbe Index, and ensuring material compatibility and safe hydrogen concentration. Although gas pipelines can transport higher concentrations of hydrogen, including up to 100%, the allowable level for distribution networks is expected to be limited to 20% to accommodate the existing customer gas appliances in use.

The following equipment limitations that are admissible with hydrogen blends will now be addressed.

Gas Turbines

There are two types of gas turbines based on their combustor system: premixed and diffusion. Incorporating hydrogen into natural gas is more difficult for premixed systems, as it can result in increased NOx (Nitrogen Oxides) emissions and higher moisture content, which can reduce the lifespan of components due to the increased flame temperature. As a result, turbine manufacturers have set strict gas specifications for 0-5% hydrogen blends.

However, more recent studies suggest that modern turbines can accommodate up to 10% hydrogen. To handle higher hydrogen concentrations, retrofitting of gas turbines may

3. Depends on different concentration of gas compositions there is different gas quality in terms of energy value and density
4. European Association for the Streamlining of Energy Exchange

2. Methodology

be necessary, including modifications to the fuel gas supply system, valves, seals, and structural components. To avoid flashback and excessive flame temperatures (NOx and overheating of turbine sections), burners may need to be replaced if the hydrogen concentration exceeds 30%.

Gas turbine original equipment manufacturers (OEMs) such as General Electric (GE), Solar, Siemens, Alstom, Kawasaki, and Mitsubishi have experience in utilising hydrogen-blended fuels, with varying hydrogen concentrations ranging from 5% to 75% and 100%. Manufacturers are currently conducting ongoing tests on these gas turbines, and some turbines can now consume up to 75% hydrogen in the fuel mixture. The OEMs intend to achieve 100% hydrogen combustion capability by 2030, with some manufacturers, including Kawasaki, having already conducted successful tests on burning 100% hydrogen.

Boilers (Burners)

The HyTest experiments on domestic boilers showed by adding 20% hydrogen (in volume) to natural gas, there was no increase in NOx emissions, rather an average 37% reduction was observed for domestic boilers. However; when hydrogen is added to natural gas, up to 70-80% by volume, the flame temperature and NOx emissions increase as the WI drops and the thermal input decreases [4]. The WI reduction can be compensated by fuel adaptative control to maintain the required fuel: air ratio and power at a consistent level.

Reciprocating Gas Engines

Stationary engines installed in the industry are equipped with a power control to maintain a constant power output e.g., when the gas composition changes. If the change in gas composition is too large, then the control system will shut the engine down.

Almost all engines are equipped with sensor-based control systems, that is primarily intended to keep NOx emissions constant in response to disruptions in the operation of the gas engine, including gas quality.

CNG Storage Tanks and CNG Engines

Compressed natural gas/biomethane (CNG) is being increasingly used as an alternative to conventional fuels such as petroleum for running spark ignition engines.

CNG Engines

Blends of compressed natural gas with hydrogen (HCNG) ranging from 0% to 20% hydrogen can be utilized in conventional internal combustion engines without requiring tuning. Blends with hydrogen concentrations above 20% necessitate engine retuning.

CNG Tanks

According to the type certification of CNG tanks required under the regulations on admissible hydrogen with natural gas, the maximum allowable hydrogen percentage is 2% due to the limitations of CNG tanks. Modern CNG tanks in Europe employ steels that can accommodate higher than 2% hydrogen concentrations [5]. It would be necessary to assess whether any older fuel tanks still in operation require replacement.

2.1 Qualitative Data Analysis

The first section of the qualitative questionnaire focused on customers' existing equipment, such as:

- What current fuels were been used in the plants?
- What was the minimum and maximum capacity of the industrial units?
- What gas fuel-based equipment was used onsite?
- What was the current capability of the existing equipment using hydrogen (from 0% to 100% hydrogen)?
- The geographical location of the plants to see how far they were from the gas network?

The second part of the questionnaire focused more on understanding the customers' requirements to help them meet their net-zero carbon targets, via the transportation of renewable gases to the end-use points via existing gas infrastructure.

Finally, we undertook a rigorous analysis of the data collected to ensure it was reliable and valid, which included actions, such as:

- Cleaning the collected data to address any missing, inconsistent, or duplicate responses.
- Validating customers' responses by checking the accuracy of data from OEMs
- Identifying anomaly data and investigating unusual patterns in the data.

2.2 End-Users Categorisation

Electricity-generating power stations and large industrial customers are also directly connected to the gas transmission network. All industrial/ commercial/residential, small to large end-users are connected to the gas distribution network [6]. Based on the gas consumption capacity of the end-users, Gas Networks Ireland categorises them into the following groups: Large Daily Metered (LDM), Daily Metered (DM), and Non-Daily Meter (NDM).

- LDM: Annual Gas Load > 57.5 GWh
- DM: Annual Gas Load > 5.5 MWh and < 57.5 GWh
- NDM: Annual Gas Load < 5.5MWh

Figure (2) shows the categorisation of gas customers in Ireland. 42 LDMs and 270 DMs were surveyed. The LDMs categorised in different segments as it is shown in the chart below. Examples of LDMs include agri-food plants from the agriculture sector, industrial units such as pharmaceuticals and chemicals and finally power plants burning natural gas for generating electricity.

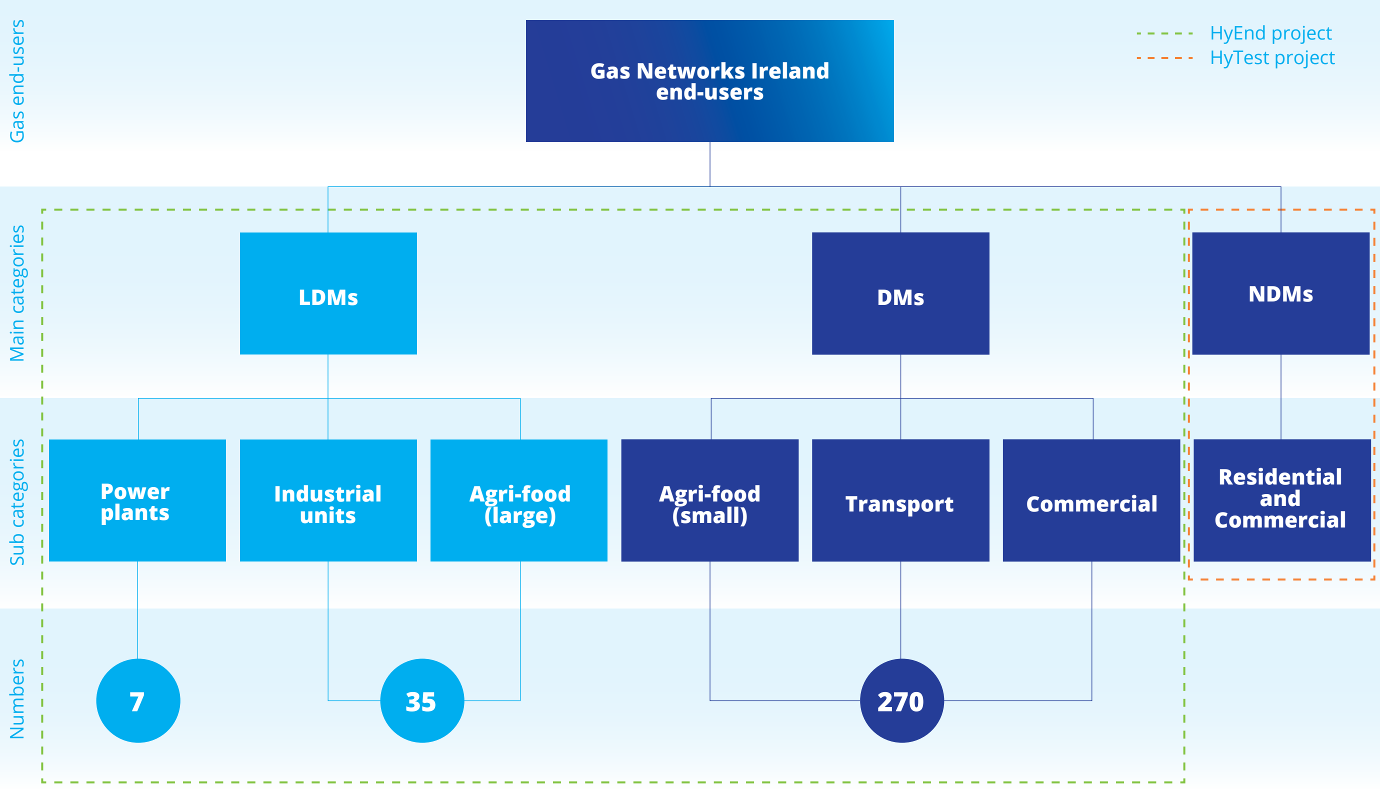


Figure 2. The categorisation of the LDMs and DMs gas users in the Irish energy system

2. Methodology

2.2.1 Power Plants

Shippers are retail market players that sell gas and provide services to end users, i.e., gas customers. Shippers include suppliers and some large end users such as power stations. Due to the volume of gas these power stations consume, they can purchase gas directly from the wholesale market and transport gas to their sites to facilitate the generation of electricity via the gas transmission system [6].

Item	Gas Point	Location	Capacity [MW]	Connection
1	Aghada	Aghada County Cork	719	Transmission
2	Great Island CCGT	Wexford	464	Transmission
3	Huntstown	Navan Road	337+408	Transmission
4	Dublin Bay	Pigeon House Rd, Dublin 4	415	Transmission
5	Poolbeg CC	Pigeon House Rd, Dublin 4	234+234	Transmission
6	Tynagh	Derryfrench, Loughrea, Co. Galway	389	Transmission
7	Whitegate	Whitegate, County Cork	450	Transmission

Table 2. List of gas fired power plants in Ireland [7]

Seven gas fired power plants have been identified across the country. Figure (3) shows the locations of the power plants on the Irish gas network. Table (2) provides more technical and geographical information.

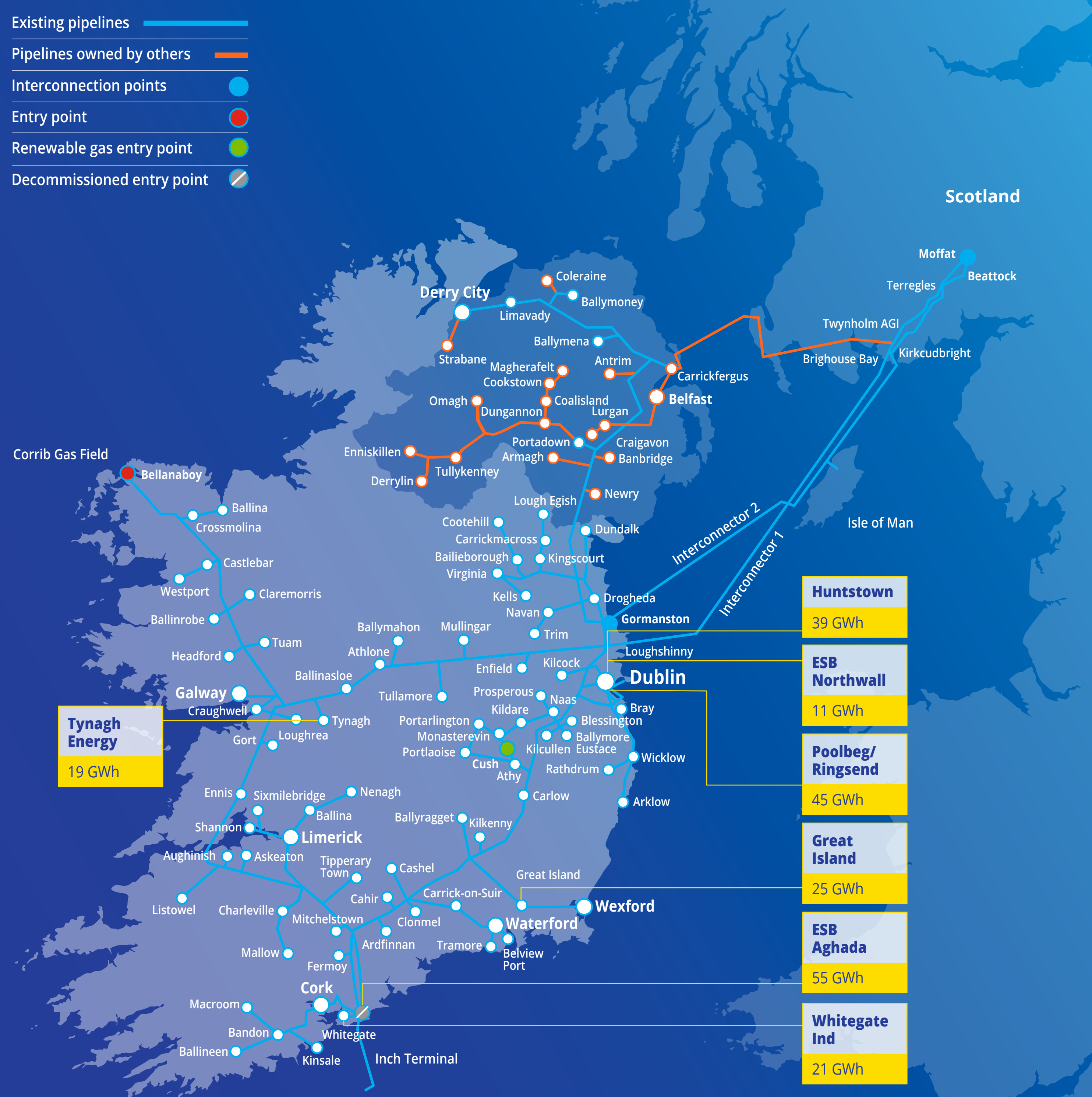
2.3 Results of admissible hydrogen within end-users in Ireland

The survey analysis and data collected from 42 LDMs and a sample of 270 DMs found that many end-users' equipment connected to the distribution network can handle a blend of up to 20% hydrogen. This information demonstrates the feasibility of introducing up to 20% hydrogen blends by volume as a viable alternative to natural gas in Ireland. Furthermore, most end users (LDM and DM) connected to transmission and distribution pipelines do not have any critical issues using a 20% hydrogen blend.

Gas power plants however are currently limited to using a 20% blend of hydrogen with their existing turbines due to concerns about NOx emissions and combustion flame adjustments. Out of the 42 LDMs connected to the pipelines, there are seven gas-fired power plants supplied with natural gas by the transmission network in the Republic of Ireland (ROI). Three of them can use a 5% hydrogen blend with minor modifications to their gas turbines. Three plants are under investigation to upgrade their combustion systems to be able to burn up to 40% hydrogen blends by 2030.

As it can be seen in figure (4), excluding power plants, LDMs are categorised mainly as agri-food plants, and the pharmaceuticals, and chemical industry sectors. Natural gas is primarily used in these plants for heating purposes through gas boilers, as well as for generating electricity through CHP plants. Reciprocating engines are the driving system used in most of the LDM CHP plants to generate power, and according to the study these engines are capable to use of up to a 20% hydrogen blend. Some factories active in agrifood industry produce biogas from their food factory waste, which is then burned in their CHP plants to generate electricity. This biogas generated by LDMs can be converted to biomethane by filtering and eliminating about 50% carbon dioxide (CO_2) by volume. The resulting CO_2 can be blended with excess renewable hydrogen to generate synthetic gas methane as a sustainable backup of energy for seasonal storage or during an energy crisis.

Figure 3. The location of the seven gas fired power plants on the Irish gas network



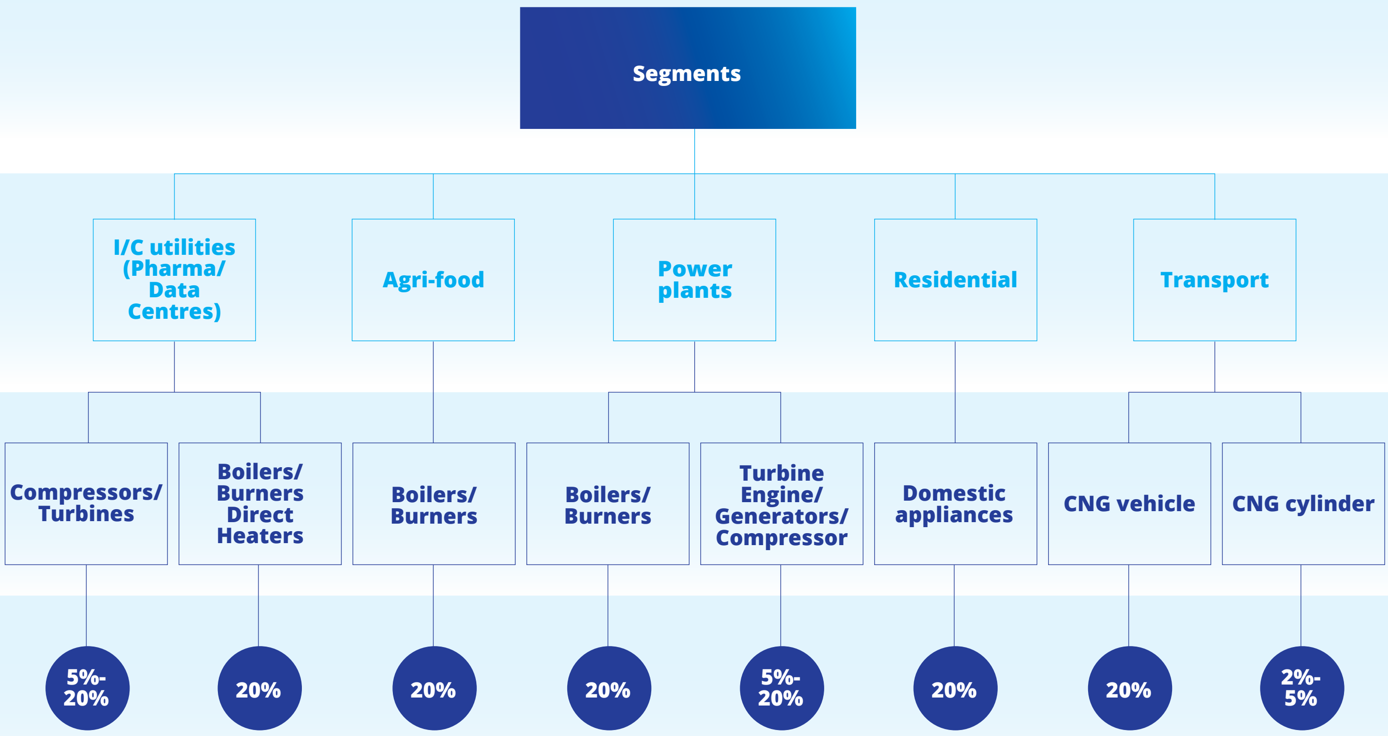


Figure 4. Desktop results of the end-users' limits in admissible hydrogen

UN Regulation No. 110 stipulates that compressed tanks in Compressed Natural Gas (CNG) vehicles (as end-users) have a hydrogen limit of 2–5%; most current gas turbines were specified for up to 5% hydrogen, but with some modifications, they can be increased up to 10%. Some new or upgraded devices, such as burners, vehicle engines, and boilers, will be able to reach hydrogen concentrations of up to 20%.

After analysing the surveys and end-users' responses to the questionnaire, the hydrogen blend limitation has been mapped on the transmission gas pipelines. Figure (5) shows that 90% of LDMs can operate up to 20% hydrogen blends (highlighted in dark green) and 10% of LDM end-users are not capable of taking more than 5% hydrogen blend with natural gas.

Capability of Large Industrial End-Users in Using 20% Hydrogen Blend

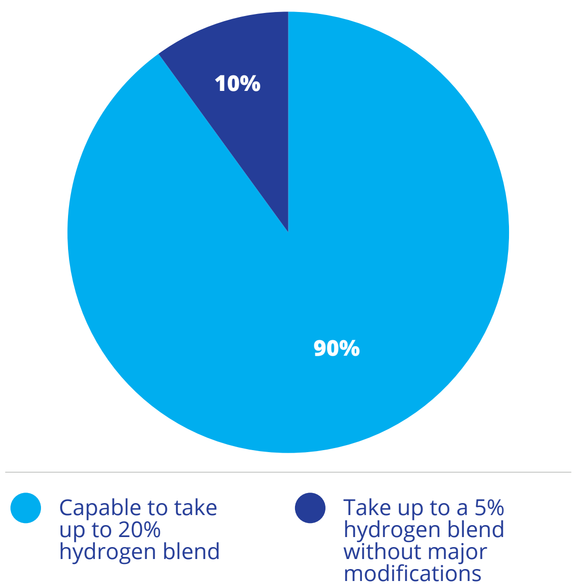


Figure 5. Admissible hydrogen blends in LDMs on the transmission gas network

3 Conclusion and Recommendations

The HyEnd project aimed to explore the customers' equipment requirements and limitations in using hydrogen blends and to create a database of industrial equipment currently in use by Irish end-users in different segments. This project investigated the impact of hydrogen blends (up to 20%) on the equipment settings to determine whether modifications or equipment are applicable.

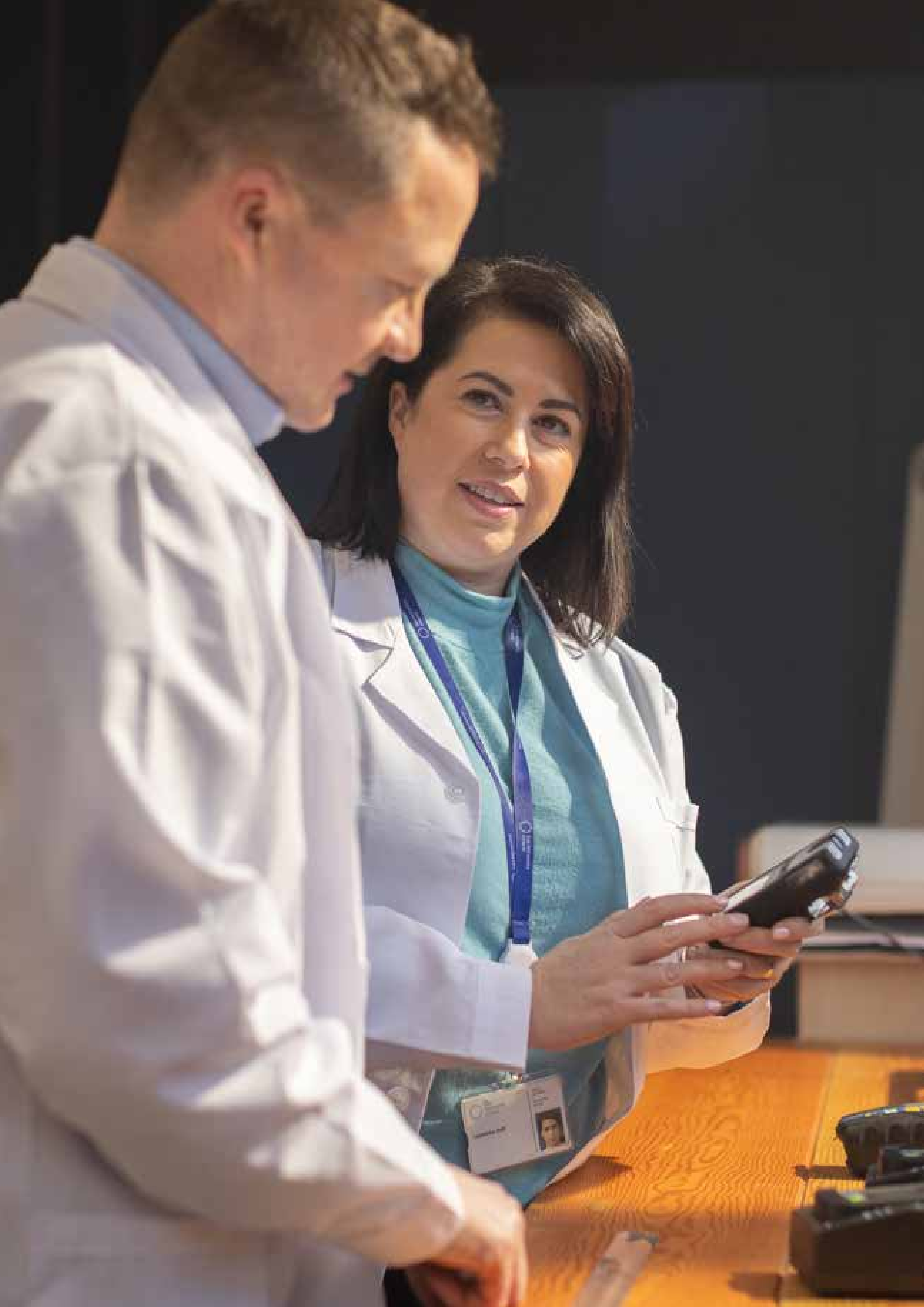
According to the results of this research project's survey, a 20% hydrogen blend is the pathway to introducing 100% renewable gas in the gas network. There are limitations for those LDMs with gas turbines in their power system, in respect of emissions and energy efficiency. While some gas power plants have concerns about emissions and combustion flame adjustments limiting them to the same blend, gas-fired power plants can use a 5% hydrogen blend with minor modifications to their gas turbines. As a result, the gas network can be adapted to deliver renewable gases such as hydrogen blends.

Regarding the future steps and feasibility of hydrogen uses by equipment, there is a need to collaborate with equipment manufacturers to enable development of appliances that can operate efficiently with hydrogen blends higher than 20% and up to 100% hydrogen. Further to the network studies, outcomes from initiatives of testing of hydrogen blends and pure hydrogen on the industrial/commercial equipment will be useful for initial hydrogen applications in regional clusters while hydrogen pipelines are pictured to become the main transportation option by 2050. In the Network Innovation Centre, further studies are planned with our academic research partners, to investigate how best the gas and power systems, including renewable hydrogen, can be integrated to keep supplying consistent energy with zero-carbon emissions.

4 Next steps

The next phases of the initiatives are listed below. These will include optimisation of the Irish gas network for incorporating hydrogen, biomethane and natural gas with a focus on the Wobbe Index and calorific value calculations while minimising emissions:

- Optimisation of the operational management of the network and consistent energy value trade off and minimising the hydrogen storage. To this, the following work-packages will be considered:
  - Optimising the H2+BiCH4+NG blends by:
  - Minimising emissions.
  - Maximising renewable hydrogen input while meeting the energy needs of end-users.
  - Minimising the hydrogen gas storage.
  - Using hydrogen storage to maintain consistent gas quality.
- Research on emissions reduction.
- Analysing hydrogen blend and pure hydrogen in power generators and industrial end-users.



References

[1] DECC, "National Hydrogen Strategy," government of Ireland, Dublin, 2023.

[2] Ali Ekhtiari, Eoin Syron, Paul O'Dwyer, Liam Nolan, "Testing of Blends of Hydrogen and Natural Gas (HyTest)," Gas Networks Ireland, Dublin, 2022.

[3] EirGrid, "Operational Policy Roadmap 2023-2030," EirGrid & SONI, 2023.

[4] "Effects of hydrogen addition on the performance and emissions of a natural gas-fired gas turbine combustor," Journal of Hydrogen Energy, vol. 38, no. 28, pp. 12269-12279, 2013.

[5] Martijn van Essen, Sander Gersen, Gerco van Dijk, Manuel Emde, "Literature review on CNG / H2 Mixtures for heavy-duty CNG vehicles," Concawe, Brussels, 2021.

[6] G. N. Ireland, "Customer Performance Report," GNI, 2019.

[7] EirGrid, "Ireland Capacity Outlook 2022-2031," 2022.

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