Hydrogen in Northern Ireland: Future Costs, Challenges and Implications

Executive Summary

As the world transitions towards a zero-carbon future, effective and economic alternatives to fossil fuels and CO_2 emitting industrial processes are essential. Green hydrogen has been proposed as a way to decarbonise many existing sectors of the global economy and for some industries such as chemicals and steel there are no realistic alternatives to the phasing out of carbon intensive, grey hydrogen and coking coal. New requirements are also emerging that require green hydrogen such as the production of liquid e-fuels for aviation and shipping as well as solutions for electricity grid challenges such as long-term energy storage or addressing constraints and curtailment.

Northern Ireland (NI) is unique in the UK with no significant use of grey hydrogen in industry and no steel industry dependent on coking coal. Therefore, NI is not obliged to go down the green hydrogen route but is able to choose the pathways that lead to decarbonisation and the best long-term economic benefit for the country. Green hydrogen does offer workable solutions for many applications from heating to transport and the first question this work sought to answer was:

> *In a competitive market, competing on both cost and non-cost factors with a wide and growing number of alternatives, is green hydrogen the best option for any **current** industries and economic activities in NI?*

The future world will see new opportunities develop as the supply and use of fossil carbon declines and concerns over energy and food security are addressed. This leads to a second question:

> *Are there new opportunities or requirements by 2050 that would require green hydrogen in NI?*

Here, the objective was to capture current developments and projections from academic literature, policy reports and industry perspectives and then to apply them to NI.

Finally, based on understanding what form green hydrogen's role will likely take in Northern Ireland and what factors drive this we sought to understand:

> *How these might be influenced, positively and negatively, by NI government policy?*

Answering these three questions is the purpose of this report. At the outset it was recognised that NI is still in the initial stages of transition to a low carbon future. For example, NI's electricity grid was built for large, centralised power generation constructed close to areas of high demand and not for a large number of smaller scale, intermittent, wind and solar farms often located away from major conurbations. Today's situation is therefore very different from that expected in 2035 and by 2050 the changes will be substantial. Published technology projections and plans for grid enhancements were assessed to get a picture of the environment in 2035 and 2050.

The cost of green hydrogen infrastructure (electrolysers and storage) and ultimately end-user prices are widely forecast to reduce but there are a large range of different views in academic, industry and government forecasts which creates uncertainty on predicting future pricing of green hydrogen. One certainty is that green hydrogen produced by electrolysis will always be

dependent on the price of electricity and the more optimistic forecasts[1] require prices to drop by a factor of ten which is extremely unlikely in a UK or NI context.

Current issues with unused renewable electricity (dispatch down: curtailment and constraints) are forecast to drop dramatically as the grid develops, new uses such as short- and medium-term energy storage or electric vehicle fleet charging and better cross jurisdictional interconnection are built. Any remaining unutilised power will attract not just hydrogen producers. Other, new activities will compete such as vertical farming which becomes more economically viable the lower the cost of electricity or political choices will be made such as the potential to address fundamental social issues such as fuel poverty through heat-pump enabled district heating for social housing.

This analysis has been based on the fundamental economics of hydrogen and focuses on green hydrogen generated through electrolysis as the most likely route to production. Ultimately, the price of green hydrogen to the end-user will be affected by initial support mechanisms (capital grants, tax credits etc.) and at some future point potentially by taxes levied to offset falling fuel duty. However, NI must take care that such short-term incentives do not lock us onto a path which in time proves to be disadvantageous given the underlying economics compared to alternatives.

At the time of writing a consultation has been launched in Great Britain around how subsidy to (limited initial) hydrogen generation may be structured under Gas Shipping Obligation (GSO). It is possible that this might be extended to Northern Ireland, and this might add a significant levy to consumer gas bills. The ambition is to reduce the cost of the generated hydrogen to that of fossil fuels. If this is ultimately enacted and extended across all production it would make hydrogen more affordable and hence attractive for some uses, transforming its projected usage. However, the costs of widening this support are likely to be very large and the scale of that subsidy may generate competition concerns unless the EU adopts a similar approach. The presumption in this paper is then that this action does not presage high general subsidy for hydrogen and that market forces, based on underlying costs, will play a determining role in the local energy market.

Key Findings

Decarbonisation of the current NI economy

Investigation of the requirements and paths for decarbonisation in NI clearly showed that given the current industry base in NI there were no cases where green hydrogen was the only option for decarbonisation, unlike in GB. The best options for **any current** NI industries and economic activities then depend on financial, environmental, security and social considerations. The picture for hydrogen has changed over the past few years and there is a growing consensus that it will have a more limited role across the economy in the UK. The recent Committee on Climate Change (CCC) seventh carbon budget[2] concludes:

> *"Hydrogen: by 2040, our Balanced Pathway sees hydrogen play a small but important role, particularly in industrial sectors such as ceramics and chemical production which may find it hard to electrify. Hydrogen also has an important role within the electricity*

[1] For example: https://www.crugroup.com/en/communities/thought-leadership/sustainability/energy-from-green-hydrogen-will-be-expensive-even-in-2050/ or https://www.pwc.com/gx/en/industries/energy-utilities-resources/future-energy/green-hydrogen-cost.html

[2] https://www.theccc.org.uk/publication/the-seventh-carbon-budget/

*supply sector as a source of long-term storable energy that can be dispatched when needed and as a feedstock for synthetic fuels. However, **we see no role for hydrogen in buildings heating and only a very niche, if any, role in surface transport**."*

The CCC's view is a strong validation of the findings from the research carried out for this report. Green hydrogen will always be an expensive fuel as it relies on electricity to power an electrolyser and associated plant which together has significant efficiency losses. In the optimum situation for green hydrogen with use at the point of production, there would need to circa double the electrical power as an input in order to provide the same energy content at point of use after efficiency losses compared to an electrification option. A more realistic scenario with compression, distribution and storage included generates a ratio closer to a factor of three. For home heating a factor of six is reasonably expected i.e. electricity → hydrogen & storage → heat *vs* electricity → heat pump, as a heat pump can lever electricity inputs, moving three units of heat into the home for every unit of energy powering it. This implies that to go down the hydrogen route there would need to be a considerable increase in renewable generation capacity with consequences for visual amenity and land use as illustrated in Figure 1 below.

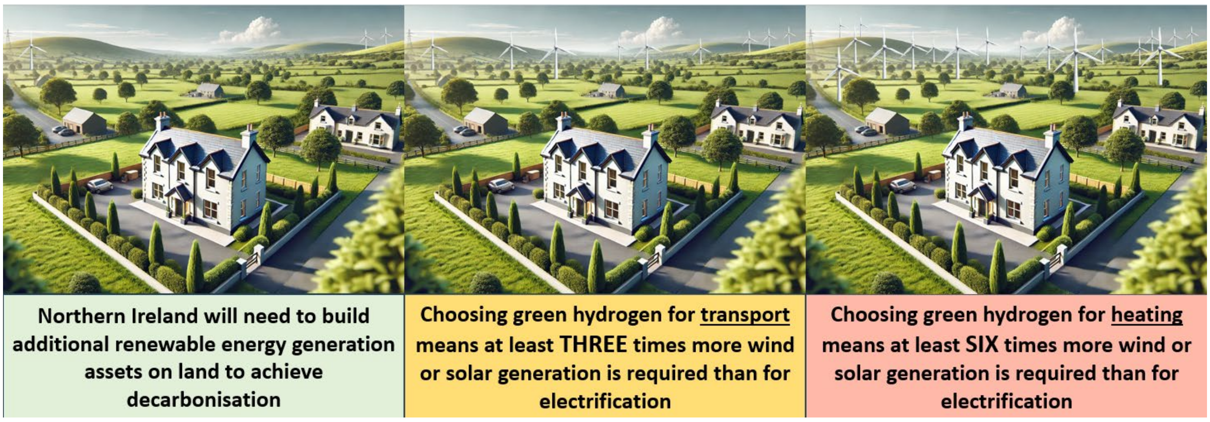

Figure 1 *Illustration of the impact on numbers of wind turbines if hydrogen was used for transport or heating in NI*

Taking a transport example and based on current lowest end-user price for green hydrogen including distribution and storage costs in GB the price equivalence to electrification is around £1.0/kWh (assuming fuel cell efficiency of 60%). For comparison, the lowest cost for eV charging in the same geographic area is £0.08/kWh (off-peak) and maximum £0.53/kWh for a fast charger. While cost of plant for green hydrogen will reduce with time and scale, fundamentally the price floor for green hydrogen is limited by the cost of electricity. As the above example is based on the use of a capital grant funded facility it is likely that the price of green hydrogen will not be reduced substantially when support schemes end.

There are a few companies in NI that have high heat requirements currently met by natural gas and a need for a transition using a drop-in replacement for natural gas. In both cases NI has the local resources to meet this need with biomethane at a much lower energy price and avoiding the high capital costs and additional handling challenges that adoption of hydrogen would incur. In the first hydrogen allocation round (HAR1) the strike price for hydrogen in the UK was set as £241/MWh[3], this compares to a production price for biomethane in NI of £90 - £140/MWh[4]. The strike price for hydrogen will drop but without some form of continued price support will always be the innately less competitive option due to the dependency on electrical power.

[3] https://www.gov.uk/government/publications/hydrogen-production-business-model-net-zero-hydrogen-fund-shortlisted-projects/hydrogen-production-business-model-net-zero-hydrogen-fund-har1-successful-projects

[4] https://www.economy-ni.gov.uk/consultations/developing-biomethane-production-northern-ireland-call-evidence

Many suggestions have been put forward for lowering the cost of green hydrogen to end users such as use of constrained electricity, construction of pipelines, reduced grid charges etc. While these might reduce costs, many could equally be applied to the broader electrification of the economy with a better economic outcome. Also, hydrogen production would face strong competition for off-peak/low-cost electricity from other forms of energy storage, heating for social housing, and emerging industries such as vertical farming. These are discussed in more detail later in the report.

Two other points are also relevant to the need for green hydrogen in NI. The first is the pace of technology development for eVs across all classes of vehicles. Hydrogen has lost the battle for cars and vans, is falling very far behind for buses and volume orders for electric HGVs is indicating this is also an area with a better market-ready solution. The recent doubling of battery energy density and other improvements are also eating away at any nominal advantage hydrogen has for longer-duration travel and colder climates.

The second point is potential environmental impact. Hydrogen is a secondary greenhouse gas with a global warming potential (GWP-100) of 11.6 ± 2.8[5] and with a comparatively high leakage rate from distribution and use this would need to be considered for NI's greenhouse gas inventory. Also, when combusted for heat or in an engine hydrogen can produce comparatively higher levels of NOx air pollution compared to fossil fuel alternatives[6]. Levels of NOx can be reduced either by hydrogen specific designs with higher air volumes or flue/exhaust gas treatment.

The stark conclusion is that any existing use of hydrogen in Northern Ireland can be readily substituted by either electricity (most likely option) or biomethane, and that every one of these will find those alternatives to be cheaper than a hydrogen-based approach.

Future uses of green hydrogen in NI

While the finding of no economically justifiable requirements in NI at present is no surprise given the failure of much cheaper grey hydrogen to penetrate fuel and heat markets over the past century, the study did establish two potential future uses of green hydrogen in NI.

1) The first utilises green hydrogen as a chemical feedstock that is used with NI's biogenic carbon feedstocks to create e-fuels and chemicals. Here the economics would rely both on NI's relative advantages to provide green CO_2, biomethane or biomass as well as developing very low-cost renewable electricity. In practice this is likely to be a large scale (>500MW) electrolyser with a private wire connection (to avoid grid-related costs) to a fixed-bottom, offshore wind farm with a high-capacity factor. To be viable the electrolyser would need to be also directly linked with the e-fuels/e-chemical plant to minimise storage and transport costs and where the waste heat and the oxygen co-product from the electrolyser can be valorised to maximise economic gain and assure cost competitiveness within global markets.

2) A future energy system dependent on renewable forms of electricity generation will have to solve the problem of long-term and inter-seasonal energy storage, especially if energy security is a major driver. Low solar generation in winter coupled to week to month long periods of below normal wind speeds necessitate some form of alternative energy supply. Green hydrogen could be that vehicle but would need large capacity gas cavern

[5] https://www.nature.com/articles/s43247-023-00857-8

[6] https://uk-air.defra.gov.uk/assets/documents/reports/cat05/2411071337_H2_combustion_note_proof.pdf

storage to be feasible and would have to be more economic than the alternative for NI which would be biomethane.

Both options relate to the longer stem storage and densification of energy which is needed within the wider economy to provide resilience and support sectors such as shipping and aviation. This is not to discount that there may be unique scenarios where an organisation can effectively utilise green hydrogen or its co-products, oxygen and waste heat. This includes some areas of transport. However, such scenarios are in themselves likely to be relatively small scale and unlikely to be economical unless integrated as part of a wider system.

The competitive analysis

The table below summarises the competitive analysis.

Use Case	Primary Competitor(s)	Likely Future Scale of H2 (NI)	Comment
Energy Storage	Short – battery, compressed air, gravity, flywheel Medium: pumped storage, Long: biofuel, interconnectors	Potentially high	Likely long duration storage is an option but need gas caverns or e-fuel production infrastructure. Might complement e-chemicals/biorefineries. Strong competition from biomethane. Needs in-depth study to determine best route, especially given political/public pressure against gas caverns.
Industrial Heat	Electrification Biomethane Thermal Batteries Biocoal	Low	Alternatives are less expensive in all applications including for energy intensive industries. Biomethane is a drop-in replacement for natural gas.
Domestic Heating	Heat Pump, Biogas,	Low	Heat pump 6x more efficient than hydrogen and lower risk.
District/Public building / Commercial heating	Hot water, heat pump	Low	As for domestic heating efficiency advantage is 3-6x that of hydrogen.
Transport: Air	Biofuels	Potentially high	Aviation fuel will need to be replaced by a synthetic aviation fuel (SAF) as electrification and hydrogen lack the volumetric energy density and storage advantages of a liquid fuel.
Transport: Marine	Biofuels. Electrification of inshore vessels	Potentially high	Synthetic/e-fuels as hydrogen vector are most likely. Hydrogen on a boat possible but higher risk and more expensive.
Transport: Buses	Battery, biofuels	Low (except in niche areas)	Substantial improvement in battery technology has mitigated concerns over range and charging for latest generation of buses. Potentially niche roles where rapid turnaround required or for long distance journeys.
Transport: HGV	Battery Bio/Synthetic fuels	Low	Limited scope for long distance journeys in NI and UK owing to geography. Improvements in battery technology has extended range and reduced charging time. Hydrogen HGVs

			double the cost of eHGVs and three times higher running costs.
Transport: cars / vans	EV	Low	eVs have big efficiency and cost advantage. Market adoption of eVs is almost 100% of low-carbon vehicles.
Non-Road Mobile Machinery	Battery, biomethane, e-fuels, tethering to grid	Medium	There may be a requirement for hydrogen in remote from grid locations, but need can probably be met more cheaply with alternatives.
Synthetic fuels and chemicals	None	Potentially high	Specialist synfuels such as fuel for vintage cars not replaceable. Higher value-added chemicals and associated products.
Agriculture	Battery, biomethane, bio and e-fuels	Low	Better options that are cheaper.
Islands	Wind/solar/battery mix	Low	Limited requirement in NI.
Export	None	Low	Unlikely to be cost competitive compared to countries with low-cost renewable electricity, lower operational costs and cheaper land prices.
Byproduct: Oxygen	Existing suppliers	Medium	Potential for wastewater treatment, Oxyfuel combustion and in chemicals industry.
Research and Educational	None	Medium	Main requirement will be for businesses that develop products that use or enable hydrogen.

This review of potential use cases thus reaches a robust conclusion: in the same way that today hydrogen is not competitive against fossil fuels, so it will struggle against low carbon (mostly electrification based) solutions in the future. Many uses, such as domestic heating, that hydrogen could technically fulfil are found to be unlikely to be economic. In part this reflects the need to store and transport hydrogen, costs which have perhaps been under recognised in the past. A corollary of this is that where hydrogen is used, we might expect its generation to be close by, typically onsite. In turn this indicates that a pervasive distribution hydrogen network, spanning Northern Ireland, is not justified. The case for larger transmission pipes is dependent on assumptions around its role in energy storage, and this is developed in the first use case in the main report and discussed further below.

Note too, that while hydrogen's innate characteristics are, as an element, permanently fixed, limiting the potential for transformational change in its use, competing technologies are showing continuing progress. In many cases this improvement is transformational, with batteries for example reaching levels of energy density that appeared improbable in the recent past, while slashing costs. It follows that, other things remaining constant, the scope for hydrogen is more likely to narrow than widen. Thus, major infrastructural investments in hydrogen may only have a short life as has been found for hydrogen car refuelling.

Ultimately the case for hydrogen is intimately linked to the extent of future bifurcation of the cost of electricity. Off-peak electricity pricing has traditionally been based primarily around recovery of the related marginal cost, primarily the (fossil) fuel cost. This sets a floor for the input cost for generating hydrogen, one which is then necessarily above competing fuels.

For energy storage using hydrogen, the round-trip efficiency of electricity to hydrogen, storage and then electrical generation is c.36% with comparatively expensive storage as well as fuel-cell costs for electricity generation (see section 4.2). This compares to grid-scale battery storage round-trip efficiency of 80-90%. Clearly, but for the need for low carbon solution, using hydrogen for short-term energy storage would be strongly uneconomic. However, long-term and inter-seasonal storage has only a very limited array of options and therefore the high cost of hydrogen energy storage maybe justified or unavoidable. In general, where fossil fuels have dominated, generation electricity storage has been minimal as inefficiencies act to further raise the cost of the returned electricity. As a result of high costs, the use of electricity has traditionally been constrained to premium uses.

The impact of renewables, with a zero-fuel cost, upends this simple relationship. If there are frequent periods of very low (or even nil) cost electricity, new ways of using it will emerge. Heating water is an obvious mechanism, as water has a very high ability to store energy (requiring 0.07MWh to raise the temperature of a cubic metre by 60ºC), has low capital costs, is safe and easily integrated into everyday usage. A single insulated tank can then replace individual boilers and heating appliances in an apartment block or service a district heating scheme. The appeal of free heat and hot water would of course be so compelling that quickly there would be sufficient demand to consume all 'free' electricity. The ultimate outcome will be a market equilibrium where at least some payment will be made.

The suggestion that current issues around the grid's inability to manage all renewable energy supply will mean that there will be ongoing surpluses of such 'free' energy is thus misguided. Hydrogen will have to compete in the market for its electricity input, and this competition will include storage solutions, potential export via interconnectors and new demand side innovations. The development of sophisticated trading, at the market level and tariffing / smart metering at the user level, makes this vision to 'use all electricity' a reality.

Implications for Policy

This report does therefore offer a 'reality check' on the medium-term prospects for hydrogen in Northern Ireland. What the gas will likely do in the future is a very small subset of its broad capabilities, reflecting inevitable efficiency losses and costs around its production, storage, transport and ultimate use.

Widespread gas use in a low carbon future is then likely dependent on biomethane solutions where Northern Ireland benefits from a favourable environment. Consideration of the future of the existing gas network should focus on this while noting that in the longer-term, by 2050, that electrification of heat and the higher price that e-fuels and chemical industry will pay for biogenic carbon will probably mean that most, if not all, domestic use will be curtailed. This outcome will open additional opportunities for NI-based hydrogen production that may be necessary for the new industry plants that convert biomethane into fuels or chemicals.

This report sees a potentially viable, future use of green hydrogen in two, large-scale uses: energy storage and e-fuels/e-chemicals. The happy geological accident of the presence of major salt deposits around Islandmagee could provide for the large, safe and cost-effective storage of hydrogen (and other renewable gases) in gas caverns close to major potential users including ports, industry and, notably, power generation facilities.

This asset is of potentially very high economic value as it provides security of supply for energy, fosters the development of greater renewables, widens choice for business and industry, and directly drives investment, jobs and incomes in Northern Ireland. It can thus both strengthen and de-risk key future sectors of the local economy. Without some form of long-term energy storage or large increases in interconnector capacity then NI will be vulnerable to electricity shortages when renewable generation is low for days or weeks. Serious consideration needs to be given to development of this NI/UK/Ireland critical asset as NI moves towards 2050 and away from fossil fuel use.

Post 2050, the use of the caverns for energy storage could act as a gateway for other hydrogen uses to emerge and would also open the potential for expansion of this hub, with arms (pipelines) extending out across Northern Ireland and perhaps cross-border. An east coast hydrogen pipeline (Larne to Waterford) would act to add storage and allow cheaper transmission, bringing in more ports, airports, power stations, industry and population centres. This increased scale and diversity of user would reduce dependence on a single use and mitigate adverse impacts around timing, including seasonality, of use, which reduces average costs to users, improving sustainability. Linkage with Scotland could also bring benefit, though here a likely strong competitive position in renewables in Scotland may result in reducing local generation of hydrogen, though this is dependent on a wide raft of factors beyond the remit of this study.

Most importantly hydrogen storage keeps options open when changed circumstances are possible.

Policy Imperatives

The study highlights the need for further consideration around core issues:

- The extent to which hydrogen importation and/or generation occurs in Northern Ireland for the future uses identified, including the siting of necessary components and wider infrastructure for a hydrogen production/distribution hub
- The value of energy resilience, security and diversity of supply including understanding the most cost-effective solution for NI – green hydrogen, biomethane, another biofuel or e-fuel or greater interconnectivity to other countries
- The wider all-island perspective on hydrogen use, in particular the merits of a cross-border pipeline that could reduce costs and enhance supply if inter-seasonal energy storage or e-fuel production were to develop on the island
- The future of the existing gas distribution network in Northern Ireland and development of the local electricity grid, including large scale energy storage
- The tax treatment of low carbon uses, subsidies and the relationship with EU principles and policy, driving the hydrogen context in Ireland
- Avoidance of unnecessary levies on consumer bills in NI for supporting hydrogen production for use cases that are uncompetitive with other options and economically unsustainable in the longer term
- Creating a competitive market, for example requiring storage to be price regulated or be fully independent, to avoid market distortions.

Those reviews should inform supporting strategies, across the wider economic development front towards encouraging electrolyser production, maintenance and supply chains, supporting research and development, and enhancing green hydrogen skills in the workforce. This should be developed in tandem with industry and co-exist with an inclusive public engagement.

Conclusion

Green hydrogen is not an economically sensible route for the decarbonisation of any sector of the Northern Ireland economy today. Hydrogen will always be substantially more expensive than the electricity needed to produce it due to the many efficiency losses. Replacing current energy used with hydrogen will require at least twice as much generation capacity as electrification and realistically three times as much. Even with today's support schemes, green hydrogen is not really competitive compared to alternatives available in NI. Supporting hydrogen production through a levy on gas prices as under discussion in the UK could add £1m+ to major gas users[7] energy bills in NI and would be a significant burden on households.

However, green hydrogen offers considerable potential for benefit, including de-risking energy security, future industries and supply chains. In reality, this future can only be secured with action in the short to medium term, to enable major investment in globally significant capability, beyond which time opportunities will narrow as infrastructure develops elsewhere.

Storage is central to any future for hydrogen. It guarantees supply, allows its input electricity costs to be based on times where electricity demand, and hence price, is low, and ensures that economies of scale, vital for competitiveness, can be achieved. Considering how this storage might be achieved is then the primary challenge for policy. Scoping how this might be achieved is set out in the proposals for Phase 2 of this work.

Northern Ireland has a favourable endowment of renewable energy sources, but currently these are insufficient to meet the full requirements to decarbonise the power sector even before electrification of the rest of the economy. Dedicating future, large-scale offshore windfarms to power hydrogen production will be essential if NI is to play a significant part in the UK and European hydrogen-based economy.

The ultimate prize would go beyond simply aligning with net zero objectives. It would reshape and reinvigorate the Northern Ireland economy itself. However, this prize can only be achieved with parallel development of large-scale, renewable energy generation capacity, gas-cavern storage and e-fuel/e-chemical plant together with the necessary legislative and regulation frameworks as well as planning, safety and environmental approvals.

[7] This is an estimate based on a proposed hydrogen levy on gas shippers to cover the costs of the hydrogen allocation rounds (HAR1 + HAR2) see: https://assets.publishing.service.gov.uk/media/6787cbc3868b2b1923b6467b/proposed-design-gas-shipper-obligation-consultation-document.pdf