



Offshore Renewables Surplus Potential WS3 – Renewable Hydrogen

A report to the Department for the Environment, Climate and Communications

DECEMBER 2023

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AFRY and BVGA have been commissioned by DECC to provide an economic analysis of the potential for Offshore Renewable Energy (ORE) surplus

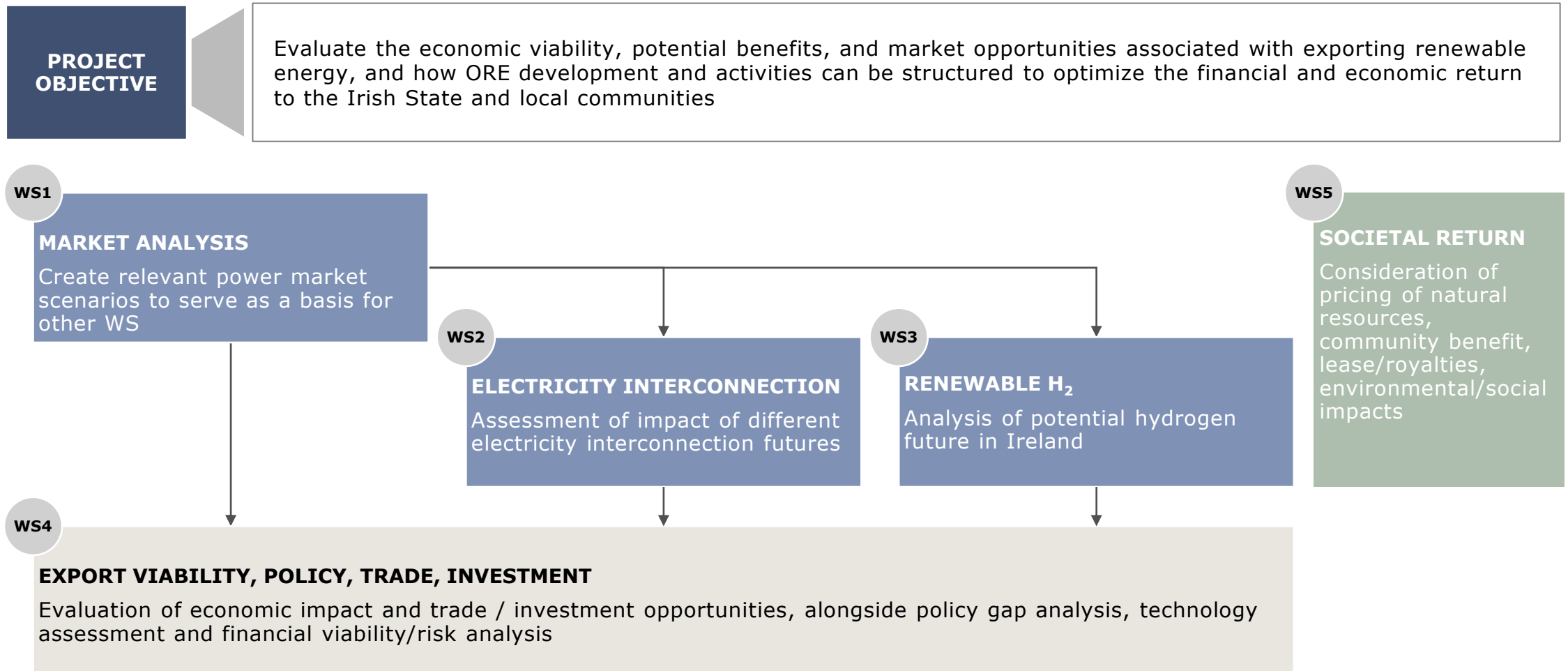
BACKGROUND

- Ireland has ambitious climate action targets for 2030 as well as a legally binding target of achieving net zero emissions by 2050.
- Offshore wind is expected to play a key role in delivering on 2030 and 2050 targets.
- Furthermore, because of Ireland’s maritime endowment, there is potential to capture significantly more offshore renewable energy (ORE) than would be needed to satisfy domestic energy requirements.
- However, it is uncertain what the optimal use of any ORE surplus might be. More specifically, whether ORE surplus should be exported as electricity, hydrogen (or hydrogen derivative) or if instead it should be ‘refined’ and used to produce new value-added products and services domestically (perhaps data centres or green steel or green aluminium).
- Consequently, the Department of the Environment, Climate and Communications (“DECC” or “the Client”) has requested AFRY Management Consulting Limited (“AFRY”) and BVG Associates Limited (“BVGA”) provide an economic assessment of the potential for ORE surplus.

SCOPE

- The broad scope of work includes the following elements:
 - Market analysis
 - Financial analysis
 - Socioeconomic impact analysis
 - Policy and regulatory analysis
 - Risk analysis
- This will be delivered via 5 Workstreams (WS):
 - WS1 – Market Analysis
 - WS2 – Electricity Interconnection
 - WS3 – Renewable Hydrogen Development
 - WS4 – Export Viability, Policy Considerations, Trade and Investment Opportunities
 - WS5 – Optimised Financial and Economic Return to the State and Local Communities

This study has five discrete but interlinked Workstreams



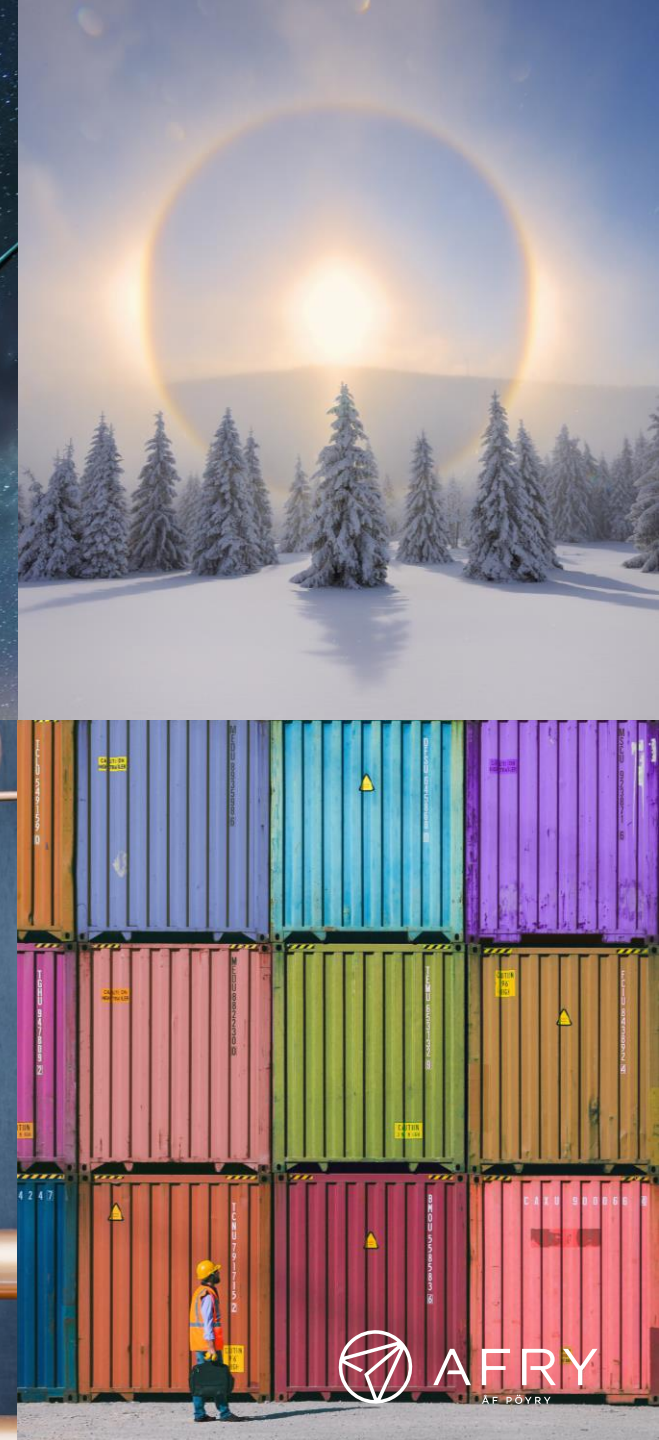
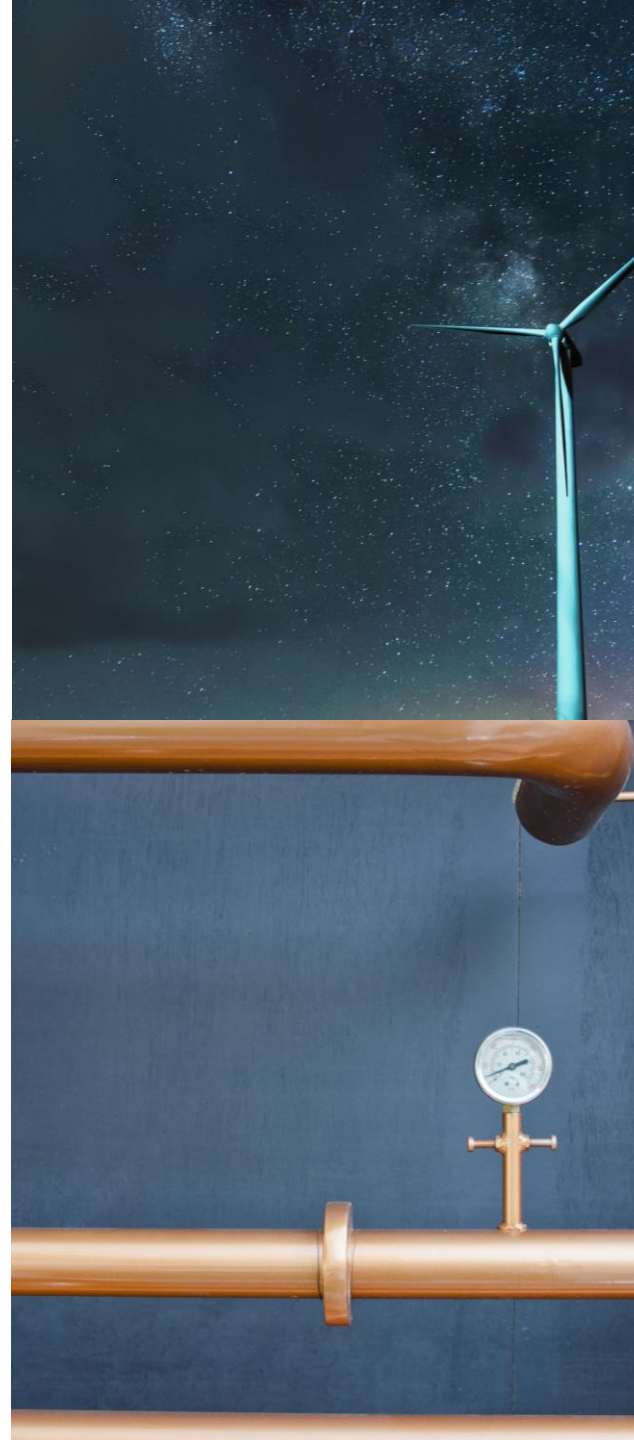
Abbreviations

ARA	Amsterdam-Rotterdam-Antwerp	FRA	France	ROI	Republic of Ireland
BBL	Barrel	GB	Great Britain	SEM	Single Electricity Market
BECCS	Bioenergy with CCS	GCS	Generation Capacity Statement	SEMC	SEM Committee
BESS	Battery energy storage system	GHG	Greenhouse gas	SOEF	Shaping Our Electricity Future
BVGA	BVG Associates	GW	Gigawatt	SS	Self-Sustaining (TES 2023 scenario)
CAP	Climate Action Plan	H2	Hydrogen	TES	Tomorrow's Energy Scenario report (published by EirGrid)
CCGT	Combined cycle gas turbine	IC	Electricity interconnector	TSO	Transmission System Operator
CCS	Carbon capture and storage	LCOE	Levelised cost of energy	TYNDP	Ten Year Network Development Plan
CH₄	Methane (i.e. natural gas)	LDES	Long duration energy storage	TWh	Terawatt hour
CHP	Combined heat and power	Li-ion	Lithium ion	V2G	Vehicle to grid
CIF	Cost, insurance and freight	LNG	Liquefied natural gas	WS	Workstream
DAM	Day Ahead Market	MW	Megawatt		
DECC	Department of the Environment, Climate and Communications	MWh	Megawatt hour		
DNZ	Domestic Net Zero	NBP	National Balancing Point		
ENTSO-E	European Network of Transmission System Operators for Electricity	NI	Northern Ireland		
ETS	Emissions Trading Scheme	OCGT	Open cycle gas turbine		
EV	Electric vehicle	Ofgem	Office of Gas and Electricity Markets		
Fe-air	Iron-air	ORE	Offshore renewable energy		
FES	Future Energy Scenario report (published by National Grid ESO)	PHES	Pumped hydro energy storage		
		RES	Renewable electricity generation		

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1. Key messages

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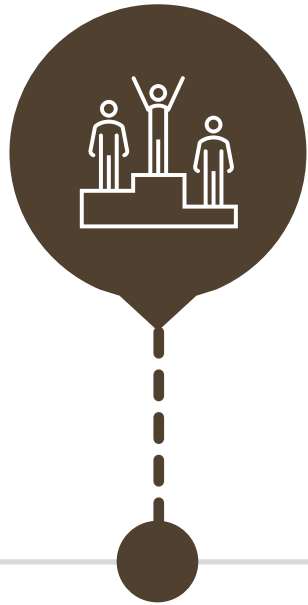
Five Key Messages to take away from this report

ORE Curtailed volumes offer the opportunity to improve the economics significantly



SMALL DOMESTIC DEMAND

Even accounting for growth, the market for domestic hydrogen demand is going to be small



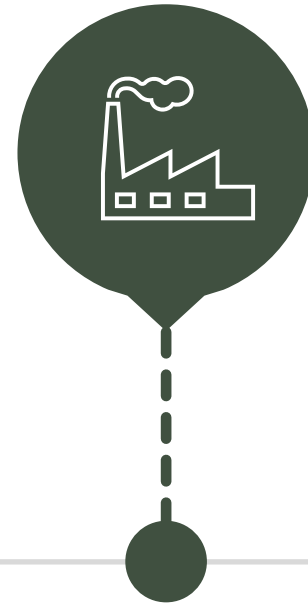
NO COMPETITIVE ADVANTAGE

Irish hydrogen competes with other European domestic production but has no clear competitive advantage



PIPELINE EXPORT COMPETES WITH SHIPPING

Produced volumes shipped by pipeline to Europe will be cheaper than global imports



NEW INDUSTRIES NEED SCALE

Ireland could use hydrogen domestically for ammonia, methanol or SAF but these would have to be large scale to compete globally



EXPORT TO THE EU VIA PIPE ROUTE TO MARKET

Credible case for export via pipe to the EU but a narrow window to take first mover advantage given other EU state plans

SUMMARY

Key Messages

- Ireland has a minor hydrogen market with uses in food, refining, semiconductor and pharmaceuticals - imported ammonia is used in fertilisers
- European hydrogen demand will outpace supply and the need for imports has been recognised for the near future
- Potential volumes of up to 93 TWh_{H₂}, could be produced by excess ORE in Ireland with large amounts available for export once domestic demand is met, but economic volumes will likely be smaller
- Hydrogen production costs from dedicated ORE in Ireland are broadly competitive globally, but with no outright competitive advantage, curtailed ORE could provide competitive hydrogen
- The opportunity presented by proximity to mainland Europe and ability to leverage cheaper piped hydrogen gives Ireland an edge over global shippers of hydrogen and derivatives
- However, mainland European domestic hydrogen production costs are likely to be slightly cheaper than importing Irish production from ORE
- There is clearly the opportunity to produce significant volumes at parity with other producers in NW Europe and as a result the key question is whether to scale up domestic industry to use that or export
- If scaling up industry Ireland will need to create megaplants for production of derivatives/products, as small plants will not be able to compete globally
- Key opportunity lies in ammonia/fertilisers as the most credible long-term option



Three emerging findings to consider in future work



Exports will require first mover advantage

The delivered cost of hydrogen from Ireland is in line with other domestic producers of hydrogen in Europe. If Ireland can get connected to a high demand market via pipeline and utilise significant curtailed volumes it will be in a strong position to sign long term contracts. Germany offers huge potential and has signalled that imports will be a part of its strategy, but competition will be fierce



Ireland will need to choose industry to support

Hydrogen could be used in a number of different industries that are currently not present in Ireland. Such industries needs will need to be considered with regard to the infrastructure to support them. Careful consideration will need to be taken to ensure the industry matches the available production profile as well as the broader skills and infrastructure available in Ireland, even before considering if such an industry would be globally competitive

Making productive use of up to 3.5Mt (133TWh) of hydrogen will require a multi-faceted approach

In order to make full use of the hydrogen opportunity from ORE in Ireland will require a joined-up delivery to maximise utility:

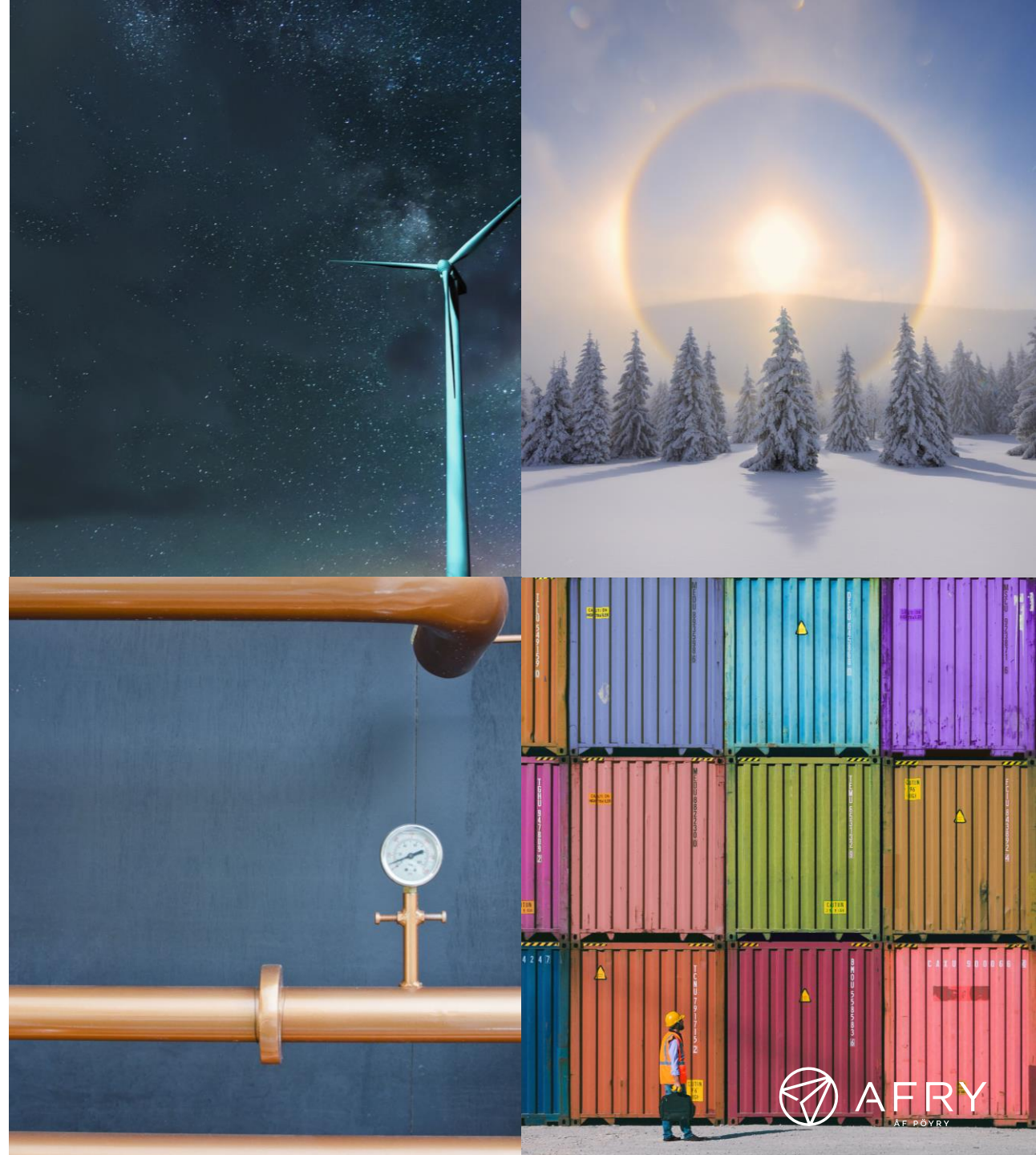
1. Domestic demand should increase significantly, and this is only possible through support of completely new high demand hydrogen industries
2. The most credible industry would be ammonia/methanol which could also satisfy domestic fertiliser demand – this industry would have to be of sufficient scale to be commercially viable
3. SAF is another possible route but would need a large and stable source of CO₂, or other carbon rich feedstock, coupled with hydrogen production to be feasible
4. Exports to Europe through a pipeline connected to Germany through the UK or France

Dedicated hydrogen production Ireland is broadly competitive and the use of curtailed renewable volumes could improve the economics along the hydrogen value chain, Ireland may consider a mixed approach to utilisation of its potential hydrogen production resource

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2. Introduction

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WS3 is concerned with the potential production of hydrogen from ORE identified in WS1 & WS2 and what should be done with it

BACKGROUND

- The assessments of electricity interconnection, renewable hydrogen and economic impact require a view of the future energy sector both in Ireland and in Europe / Great Britain (GB).
- Workstream 1 and 2 have provided a set of scenarios for ORE in Ireland and the available surplus energy that could be utilised as electricity
- The second option and focus of this workstream is to use this surplus energy to produce hydrogen
- Areas of uncertainty include:
 - The level of domestic hydrogen demand and growth
 - Evolution of industry in Ireland
 - Hydrogen production economics and derivatives
 - Delivered price of hydrogen from Ireland and major exporters
 - Cost of transport and storage
 - Requirement for supporting policies and potential subsidy
- Ultimately, the primary focus of WS3 is to create a potential route to market for hydrogen from surplus ORE in 2030, 2040 and 2050

SCOPE

- Establish domestic demand from hydrogen strategy and other documents for 2030, 2040 and 2050
- Establish European demand and consider policy and frameworks that will encourage development of European hydrogen economy
- Use inputs from Workstream 1 and 2 to quantify amount of hydrogen that would be available for export (assuming all domestic demand is satisfied first)
- Compute the LCOH and LCOA for Irish hydrogen production based on the outputs from the scenarios in WS1 and WS2
- Based on the results specify the potential routes to market and plan for hydrogen in Ireland and potential export points and destinations as well as means of evacuation from Ireland

The study uses a baseline scenario to determine the economic potential for hydrogen generated by ORE surplus and alternative scenarios to compare

BASELINE SCENARIO

- The baseline Domestic Net Zero (DNZ) scenario that has been developed for this study is a world that achieves net zero in Ireland by 2050 without a specific focus on generating an ORE surplus.
- This is a world of high renewables, significant electrification of the entire economy and a significant amount of offshore wind (21GW in total by 2050), albeit an amount that falls short of government targets for 2040 and 2050.
- For the avoidance of doubt, the DNZ scenario is not an expected or intended pathway and certainly should not be construed as DECC's baseline or reference scenario.
- Instead it is a plausible point of comparison to explore the economic potential of varying export-led scenarios.

ALTERNATIVE SCENARIOS AND THOSE MODELLED

- The alternative scenarios explored in this study differ from the DNZ scenario in the amount of ORE and electricity interconnection.
- We have explored two alternative offshore wind pathways:
 - 37GW. This pathway sees ORE reach the Government's targets of 20GW of installed capacity by 2040 and 37GW by 2050.
 - 50GW. This pathway represents a more aggressive target that sees capacity reach 25GW by 2040 and 50GW by 2050.
- We have also investigated two levels of electricity interconnection:
 - Well Connected. This pathway sees electricity interconnection reach 15% of total installed generation capacity in Ireland in the 37GW offshore wind scenario, equivalent to a little over 12GW.
 - Stretch. This pathway sees interconnector capacity reach 20% of total installed generation capacity in Ireland in the 50GW offshore wind scenario, equivalent to almost 17GW.

Hydrogen from surplus electricity is a fundamental piece of making the business case for ORE with the opportunity sized by IC economics

WS 1

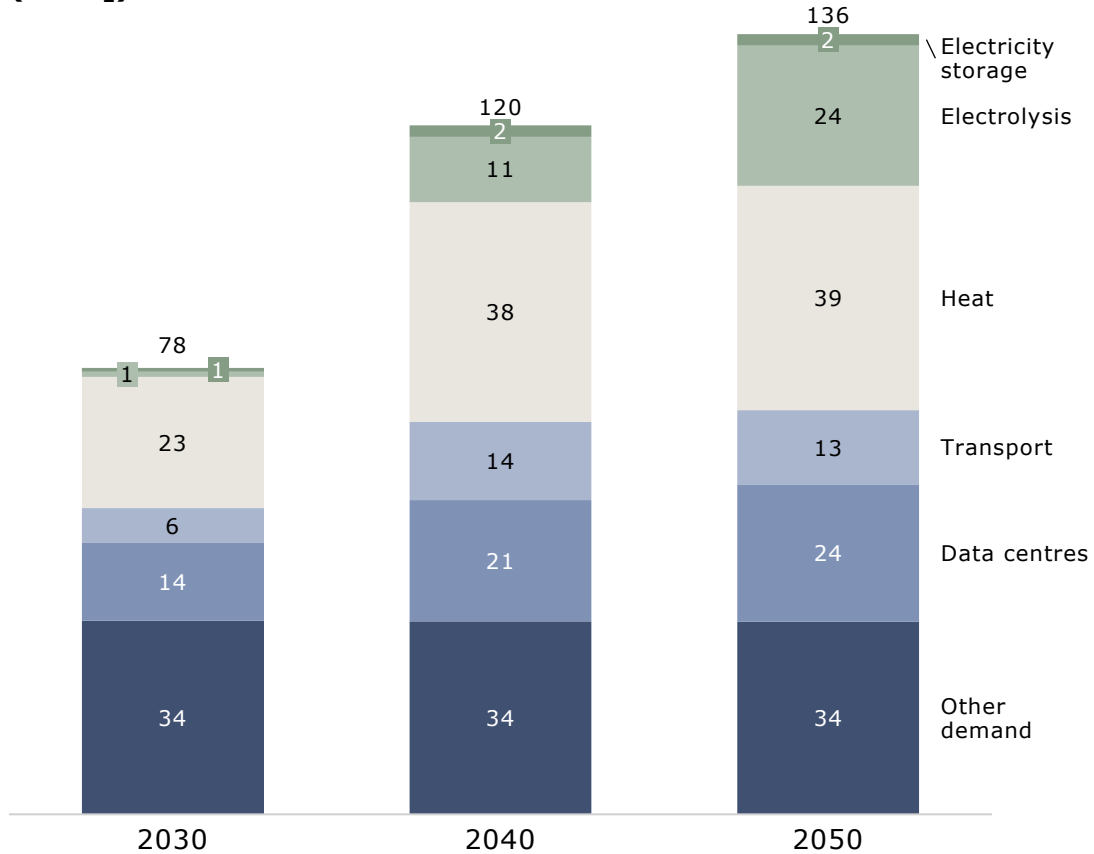
- The results from WS1 indicate that there will be an enormous surplus of energy that would be available for export or other uses in the 37GW ORE scenario
- This energy system would need to accommodate a mixture of:
 - Increased interconnection up to at least 10GW
 - A renewable hydrogen economy of at least 6GW
 - New industrial demand of at least 4GW of power (ideally flexibly)
- All of these solutions would need to be developed and be willing to support the costs of developing new offshore wind generation
- If any one of the above happen in isolation, the magnitude of what is required from any given approach could increase beyond levels that are practical.

WS 2

- The results from WS2 indicate that there is a limit of economic viable interconnection which varies by scenario
- In the DNZ scenario this is 10GW, in the Well-Connected this is 12GW and in the Stretch scenario this is 17GW
- Connections to GB and France look most promising, with longer length connections to Belgium and Spain less economically attractive
- A further observation is that whilst increasing interconnection has positive benefits for Ireland, the other markets have negative benefits
- These economic maximums therefore shape the size of the potential hydrogen economy as any excess electricity that cannot be exported will have to be used domestically or turned into hydrogen

Electricity demand from electrolysis in the DNZ scenario massively increases between 2030 & 2050 reflecting projected domestic hydrogen growth

SEM POWER DEMAND (TWh_e)



DISCUSSION

- DNZ contains a range of estimates for 2050 domestic hydrogen demand, but for this study the mid-point has been assumed
- In this scenario electricity used to power electrolyzers sees huge growth up to 24TWh by 2050 becoming material in 2040 when it is expected to account for 10% of demand
- Whilst the 2030 Climate Action Plan has suggested up to 2GW of dedicated ORE for hydrogen production the majority of demand growth is not expected until 2035+
- This will be dominated by non-power uses (industry, transport) with only 1.8TWh expected to be used in the power sector by 2050
- Hydrogen is not expected to feature prominently in space heating and light vehicle transport (either passenger or trucks)
- We have modelled baseload hydrogen production, combining intermittent electrolyser operation with storage, which meets both power and non-power domestic hydrogen demand
- We have assumed sufficient salt cavern storage to support this model without geographic and volume constraint, but this is a huge simplification

INTRODUCTION

Ireland could become a European powerhouse for hydrogen

- WS1 has shown that there is likely to be c. 800MW of excess ORE built into the energy system of the scenarios
- The modelling also suggests that after domestic demand and interconnection is satisfied there is extraordinary ORE surplus (curtailed volume) of between 49-116TWh
- If all of this surplus was used to produce hydrogen it would be sufficient to meet the current consumption of hydrogen in Germany (1.7Mt)
- What then needs to be considered is what the cost of this hydrogen would be and whether using curtailed energy or dedicated renewables is the best option for production



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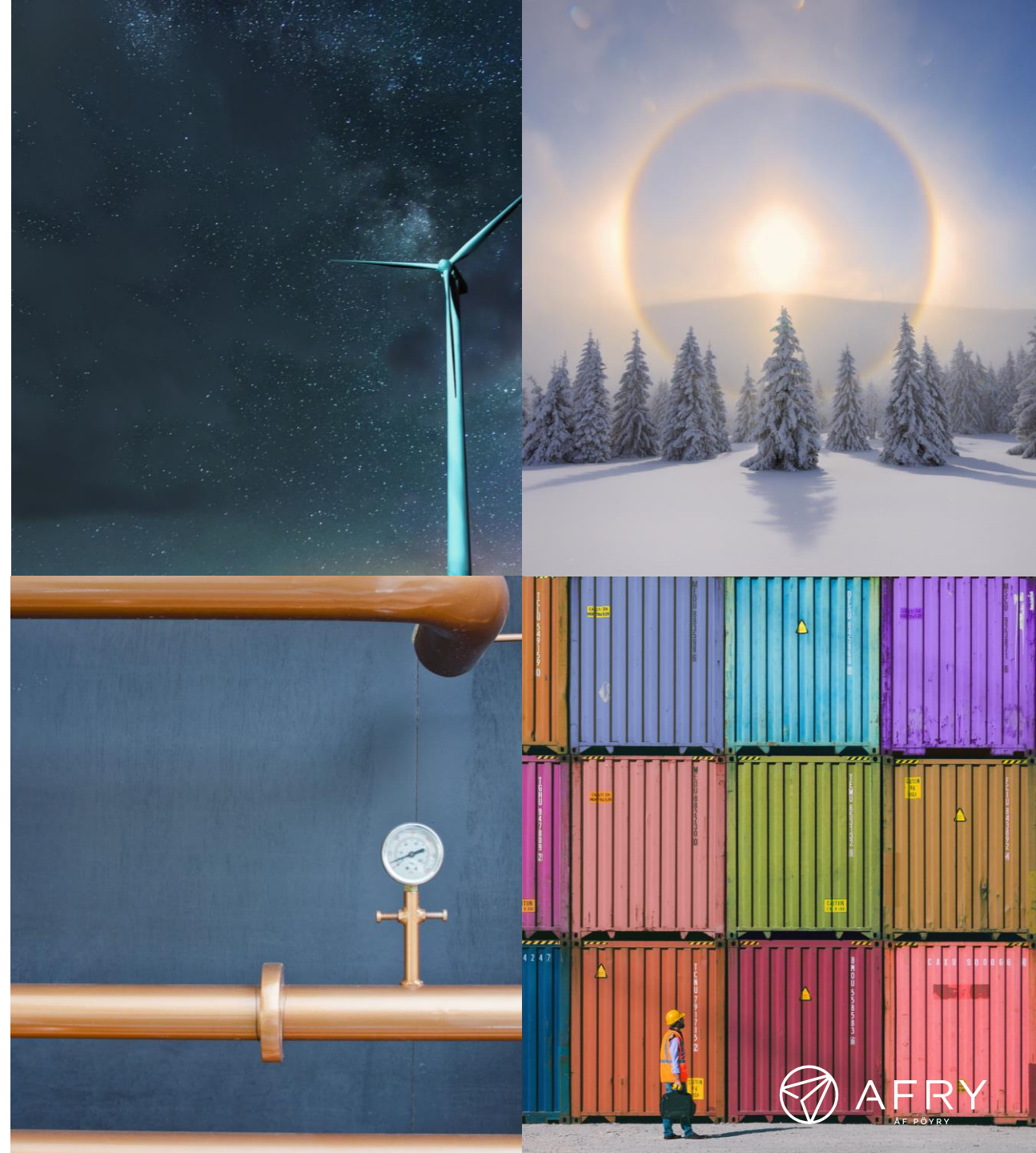
3. Policy and Regulation

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3.1 Irish Policy

3.2 UK Policy

3.3 EU Policy



Ireland has developed a national hydrogen strategy to guide developments in the sector

- Renewable hydrogen represents an opportunity for wider decarbonisation of the Irish economy; however, it remains an emerging technology with uncertainties around costs, applications, infrastructure, skills, and supply chains
- Ireland is committed to achieving net-zero emissions by 2050 and hydrogen is a key plank in achieving this as a zero-carbon replacement for fossil fuels in sectors that cannot be electrified or are hard to abate
- Ireland has set out a strategy for hydrogen that links together several areas of policy and regulation to coalesce around a shared singular vision to reduce commercial risk and stimulate private investment
- A short-medium term plan has been developed based on three 5-year plans to develop a stepped approach to switchover to a hydrogen economy
- The early phase is designed to ensure feasibility and encourage pilots with most action to develop a network and infrastructure in the second and third phases
- Guarantee of Origin policies to ensure provenance and certification for compliance with global standards is a key piece of early policy work to enable Ireland to take advantage of hydrogen in transport



This strategy pools policy from several areas to provide a framework for long term investment and certainty for industry

Shared Island Initiative - 8

Promotes cross-border renewable energy, including hydrogen. Feasibility studies for hydrogen refueling along key transport routes.

Ireland's Road Haulage Strategy 2022-2031 - 7

Includes hydrogen's role in decarbonizing heavy goods transport.

Policy Statement on Petroleum Exploration - 6

While not directly linked to hydrogen, this policy statement impacts the broader energy policy landscape

Government Statement on the Role of Data Centres - 5

Encourages renewable hydrogen usage for data centers.



1 - Climate Action and Low Carbon Development (Amendment) Act 2021

Mandates Ireland's climate neutrality by 2050, with 51% emissions reduction by 2030. Reserves 2GW offshore wind for hydrogen by 2030.

2 - Climate Action Plan 2023

Setting targets for renewable hydrogen production and zero-emission gas-fired generation by 2030.

3 - Long-term Strategy on Greenhouse Gas Emissions Reductions

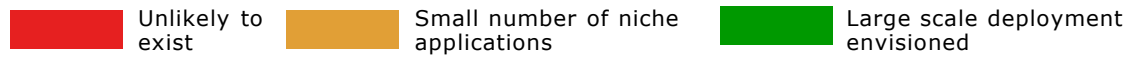
Maps pathways to carbon neutrality beyond 2030, reinforcing the National Hydrogen Strategy.

4 - National Energy Security Framework

Prioritizes hydrogen strategy development for energy security and renewables.

The strategic roadmap sets out a number of short-term actions over three 5-year plan phases and a longer-term end state

Sector	Description	2023-28	2028-33	2033-38	2038-50
Production	Renewable hydrogen produced from curtailed grid electricity or onshore renewables where available	Green	Green	Green	Green
	Hydrogen blends across the interconnectors	Orange	Orange	Orange	Red
	Renewable hydrogen from Offshore Wind	Red	Orange	Green	Green
Transportation	Trucked (non-pipeline) or onsite use	Green	Green	Orange	Orange
	Network blending	Orange	Orange	Red	Red
	Local networks/clusters	Red	Green	Green	Orange
	National hydrogen network	Red	Red	Orange	Green
	Import/Export Routes established	Red	Red	Orange	Green
Storage	Network blending	Orange	Orange	Red	Red
	Small scale storage applications	Green	Green	Orange	Orange
	Large scale storage solutions of geological scale	Red	Orange	Green	Green
End Uses	Existing Large Energy Users on gas network using GOs	Orange	Orange	Red	Red
	Heavy Land Transport	Orange	Green	Green	Orange
	Power Generation	Red	Orange	Green	Green
	Industrial Heating	Red	Orange	Green	Green
	Aviation and Shipping	Red	Red	Orange	Green
	Exports	Red	Red	Orange	Green



Source: National Hydrogen Strategy



UK policy is focussed on domestic production and consumption

- UK hydrogen policy is focussed on setting up production of both green and blue hydrogen in the UK by 2030
- It is assumed that the UK will be self-sufficient and not require imports, but there is as yet no plans to become a major exporter
- Infrastructure is likely to be built out from the identified clusters and there is a wider plan for a hydrogen pipeline system across the UK
- Various plans as to how this will be achieved are in the works but there is no current decision from government what this will look like and when it will be built
- A major decision point is planned in 2026 for heating that could spur development of the infrastructure through re-use
- In all likelihood there will not be any clarification in long term plans until after the next General Election expected in 2024



The UK has doubled its low-carbon hydrogen production targets after Russia's invasion and has strong incentive schemes to meet these targets

Macro indicators

Credit rating	AA
GDP growth (2024-2027)	1.8%
2022 primary energy consumption (TWh)	1,994
2021 hydrogen demand (mt)	0.5
2022 Renewable penetration (%)	38%
2022 Industrial power tariff	\$148/MWh
Electricity market structure	Zonal

Incentive scheme

- Net Zero Hydrogen Fund (NZHF) strands 1 and 2 - £302m
- Hydrogen Production Business Model (HPBM)
- Net Zero Innovation Portfolio – \$1.3b fund including:
 - Industrial Hydrogen Accelerator Programme – \$33m
 - H2BECCS innovation competition – \$38
 - Low Carbon Hydrogen Supply 2 – \$76m
 - UKRI hydrogen storage and distribution supply chain competition – \$5.7m
- \$23b private investment capability from UK Infrastructure Bank (UKIB), including hydrogen
- North Sea Transition Deal, 2021
- UK Low Carbon Hydrogen Standard
- Hydrogen Certification Scheme – expected 2025

Hydrogen and decarbonisation targets

- Hydrogen production / end-use targets:
 - **10GW low carbon hydrogen production by 2030, with at least 50% from electrolytic hydrogen**
 - 240-500TWh low carbon hydrogen supply by 2050
 - Hydrogen certification scheme by 2025
 - Hydrogen transport and storage business models complete by 2025
- Import / export targets:
 - No targets set
- decarbonisation targets:
 - Cut GHG emissions by 68% by 2030, compared with 1990 levels
 - Net zero by 2050 including a net zero electricity system

Key policies and projects

- Key policymaking and regulatory bodies
 - Hydrogen Net-Zero Investment Roadmap, April 2023
 - BEIS – British Energy Security Strategy, April 2022
 - BEIS – UK Hydrogen Strategy, 2021
 - BEIS – Renewable fuel transport obligations (RFTOs), 2020 – regulates renewable fuels used for transport
- Key projects / players
 - HyNet – Vertex Hydrogen
 - Zero Carbon Humber – Drax
 - H2 Deploy – Progressive Energy
 - H2 Teeside – BP
 - Tees Valley Hydrogen Hub
 - Hydrogen Super hub – SGN and others

Sources: Credit Rating: S&P; GDP growth: IMF WEO; Primary energy consumption and renewable penetration: BP; Hydrogen demand; Midrex, Global Data, AFRY Analysis; Industrial power tariff: AFRY analysis | Notes: BEIS – Department of Business, Energy and Industrial Strategy

The EU has developed a series of plans and policies to encourage and support hydrogen across Europe

- The EU has been building a complete policy and regulatory framework to govern hydrogen production, transport, storage and use cases
- This is backed up by a series of directives meant to provide a roadmap for individual state compliance to give certainty to investors and ensure compliance on the blocs course to net zero
- In addition a number of non-binding documents both at the EU and individual state level are setting out the direction of travel – whilst these do not have a legal standing they act as signals to industry to spur action and investment
- By far the most advanced policies relate to use of hydrogen in transport and it is likely that domestic production in the near term will be directed to that end use
- Industrial demand is being dictated at the national level with national governments taking a variety of approaches through national hydrogen strategies
- The main instrument governing imports is REPowerEU which allows for 10Mt of hydrogen imports as part of a strategy to reduce exposure to Russian energy supply in the EU
- This acts both an incentive to international producers but also a defined cap for domestic producers to scale their hydrogen ambitions appropriately



This extensive policy and regulatory framework is designed to support wide decarbonisation goals across member states

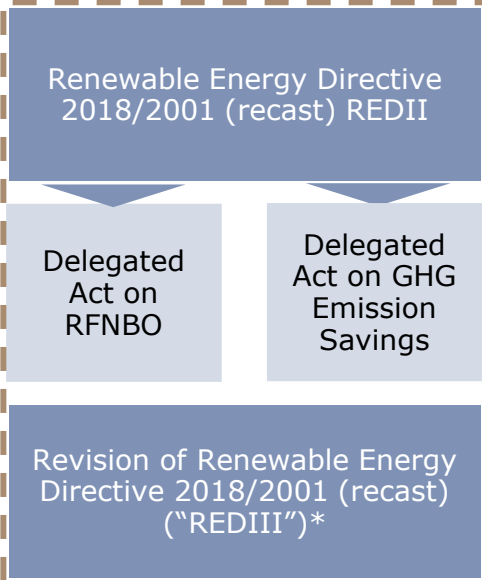
MARKET FUNCTIONING



INFRASTRUCTURE



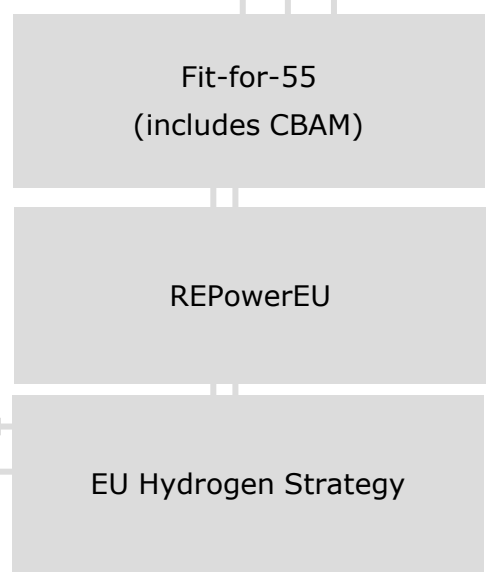
RES TARGETS



FUEL POLICIES



STRATEGIES



EU LAW*

Treaties: lay down for example the objectives of the European Union, rules of institutions, how decisions are made

Regulations: legal acts which automatically and uniformly apply to all EU countries as soon as they enter into force, without transposition

Directives: require EU countries to achieve certain result, but leave them free how to achieve these goals. Requires transposition into national law (generally 2 years after entry into force)

Decisions: are binding in its entirety and applies (and is binding) to the party it applies to

Delegated Act: legally binding acts, enabling the Commission to supplement legislative acts

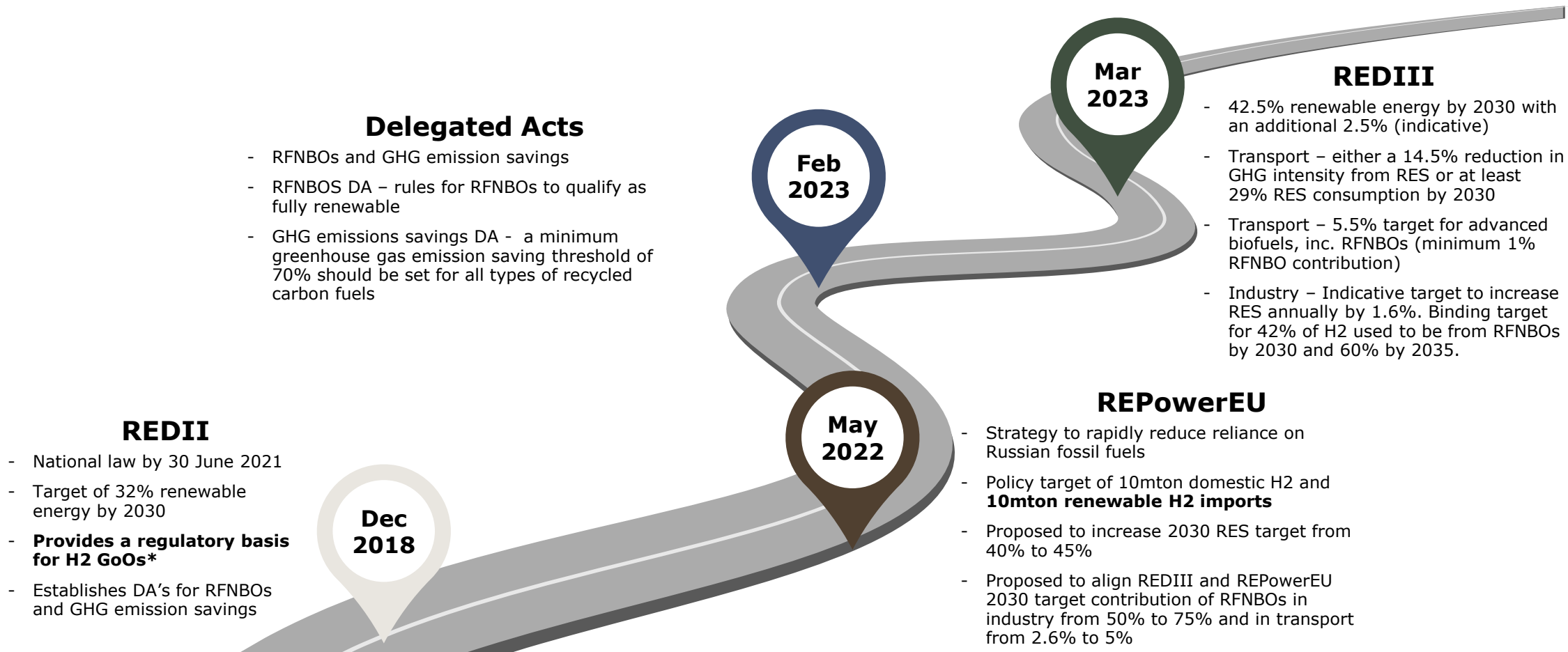
Implementing Acts: legally binding acts, enabling the Commission to set conditions to ensure EU laws are applied uniformly

Non-binding Documents: EU institutions can publish a wide variety of non-binding documents, including Communications, Recommendations, Opinions, and white-papers

 Key policy/regulation for H₂

Sources: European Commission 'Types of EU law' Accessed 22 August 2022; * Accepted buy pending publication in EU Official Journal

There has been a recent push towards targets and delegated acts concerning renewable hydrogen, including renewable imports



Delegated Acts

- RFNBOs and GHG emission savings
- RFNBOS DA – rules for RFNBOs to qualify as fully renewable
- GHG emissions savings DA - a minimum greenhouse gas emission saving threshold of 70% should be set for all types of recycled carbon fuels

REDII

- National law by 30 June 2021
- Target of 32% renewable energy by 2030
- **Provides a regulatory basis for H2 GoOs***
- Establishes DA's for RFNBOs and GHG emission savings

Dec 2018

Feb 2023

Mar 2023

REDIII

- 42.5% renewable energy by 2030 with an additional 2.5% (indicative)
- Transport – either a 14.5% reduction in GHG intensity from RES or at least 29% RES consumption by 2030
- Transport – 5.5% target for advanced biofuels, inc. RFNBOs (minimum 1% RFNBO contribution)
- Industry – Indicative target to increase RES annually by 1.6%. Binding target for 42% of H2 used to be from RFNBOs by 2030 and 60% by 2035.

May 2022

REPowerEU

- Strategy to rapidly reduce reliance on Russian fossil fuels
- Policy target of 10mton domestic H2 and **10mton renewable H2 imports**
- Proposed to increase 2030 RES target from 40% to 45%
- Proposed to align REDIII and REPowerEU 2030 target contribution of RFNBOs in industry from 50% to 75% and in transport from 2.6% to 5%

*Guarantee(s) of Origin

Recent policies have also pushed for more ambitious targets towards renewable energy share in energy consumption for end-use sectors by 2030

Policy	Overall	Transport	Heating & Cooling	Industry	Buildings	GHG emission savings	Imports
REDII	32% of all energy consumed	14%, 3.5% for advanced biofuels	40% renewable energy			70% (transport sector)	
Fit-for-55	40%	28% (13% GHG intensity reduction), 2.6% RFNBOs	1.5% annual increase	1.1% annual increase, 50% of H2 consumed to be renewable	49%	55% (overall)	0.05Mt renewable hydrogen
REPowerEU	45%	32% (16% GHG intensity reduction), 5.7% RFNBOs	2.3% annual increase	1.9% annual increase, 78% of H2 consumed to be renewable	60%		6Mt of renewable hydrogen & 4Mt ammonia
REDIII	42.5% (with additional 2.5% indicative)	29% (5.5% from advanced biofuels, inc. at least 1% from RFNBOs)		Indicative target for 1.6% annual increase, binding target for 42% of hydrogen from RFNBOs (60% by 2035*)	49%, 0.8% annual increase up to 2026, then 1.1% up to 2030.		

Notes: *20% discount in RFNBO contribution if MS national contribution to EU target is met, share of H2 from fossils is less than 23% in 2030 and 20% in 2035.

RED III sets RFNBO sub-targets for all transport fuels and industry – exceptions for industry apply

Min. 1 cal-%

RFNBO 2030 sub-target for all transport fuels

The energy content of RFNBOs is double-counted, meaning that the real needed amount is only half

The sub-target and the overall transport target take into account RFNBOs used as intermediate products in the production of conventional fuels and biofuels¹

RED III also includes indicative 1,2 cal-% RFNBO target for the maritime sector

Min. 42 cal-%

RFNBO target for industry in 2030

Covers final energy and non-energy use. Double counting does not apply. RED III does not define an EU-wide implementation for the target and Member States must implement it.

The following are not counted towards the target:

1. RFNBOs as intermediate products in conventional fuel and biofuel production
2. Hydrogen produced as by-product or derived from by-products
3. Hydrogen produced by decarbonising industrial residual gases and used to replace the specific gases it is produced from

Min. 60 cal-% by 2035

Co-operation mechanism for RFNBOs

The renewable electricity used for RFNBO production is not counted towards the overall renewable energy target of the Member State where the production occurred. Thus, meeting the overall target might be harder for exporting Member States. However, RED III allows Member States to conclude a cooperation agreement where part of the RFNBO energy content is attributed to the producing Member State. Agreements must be notified to the Commission.


- INDUSTRY RFNBO SUB-TARGET EXCEPTIONS**
- Member States can reduce the industry RFNBO target by 20% in 2030 to 33.6% and to 48% in 2035 if
 - the Member State is on track towards meeting its national contribution to the overall RED III target; and
 - the share of hydrogen, or its derivatives, from fossil fuels which is consumed in that Member State is not more than 23% in 2030 and 20% in 2035.
 - The Member State must show in their national energy and climate plans to the Commission that both conditions are fulfilled when the Member State begins to apply the reduction. The Commission will verify that the requirements are met. The reduction will cease to apply when the requirements are not met anymore.
 - The Commission acknowledges that case-by-case certain existing ammonia production facilities may not be taken into account when the RFNBO target compliance is calculated, and that Member States may rely on other sources of fossil-free energy than renewable energy
 - The exclusion of existing ammonia production facilities was driven by the French government to protect the fertiliser industry
 - The Commission has implied that the case-by-case exclusion is dependent on if the facilities have a plan or have taken decisions to reduce emissions and phase down the use of fossil energy sources
 - The acknowledgements are included in recitals and a separate declaration and, thus, their significance and evaluation are highly uncertain


1. The emissions savings achieved with RFNBOs is not considered as emissions savings of the biofuel. | 2. Must be supplied from district heating/cooling.

European Hydrogen Bank will launch tender for RFNBO production in 2023 – EU-wide import funding programme still in the works


EU has many funds and programmes to support hydrogen projects and they are varyingly coordinated by EU entities and Member States. Currently crucial programmes for hydrogen projects are the European Hydrogen Bank, initiatives under the RePowerEU plan and different state aid programmes.

EUROPEAN HYDROGEN BANK

 First auction intended to be opened in November 2023 and will award up to 800 million EUR in the form of a fixed premium in EUR/kg of renewable hydrogen produced over ten years of operation. The auction is funded through the EU Innovation Fund.

 Projects must have a minimum of 5 Mwe of newly¹ installed electrolyser capacity in a single location. Project must be located in the European Economic Area, but the final use of hydrogen is not restricted. Bid must include an off-take strategy outlining the end-use and the off-take volumes as well as how the hydrogen is delivered.

Each project may only apply for a maximum of 266,7 million EUR with a maximum bid of 4.5 EUR/kg of hydrogen produced for the fixed premium.

 The projects meeting the criteria will be awarded from the lowest bid price onwards until the total budget is allocated. If proposals have the same bid price, the proposal with the lower maximum grant requirement is prioritised.

REPOWEREU

- The RePowerEU plan also calls for accelerating hydrogen production development and imports to replace natural gas
- The RePowerEU plan, totalling ~ 300 billion EUR, is mostly funded with the Recovery and Resilience Facility funding² which provides funding to Member States to implement investments to further the green transition. Member States can also transfer funds from the funds granted under Common Agricultural Policy to support hydrogen production for fertilisers.
- Thus, RePowerEU objectives are implemented via Member State programmes which also include specific state aid. For example:
 - France has focused funding on domestic hydrogen production in France with goal of 6.5 GW electrolyser capacity by 2030
 - Germany has implemented funding programme for domestic hydrogen production as well as hydrogen imports

FUNDING FOR HYDROGEN IMPORTS

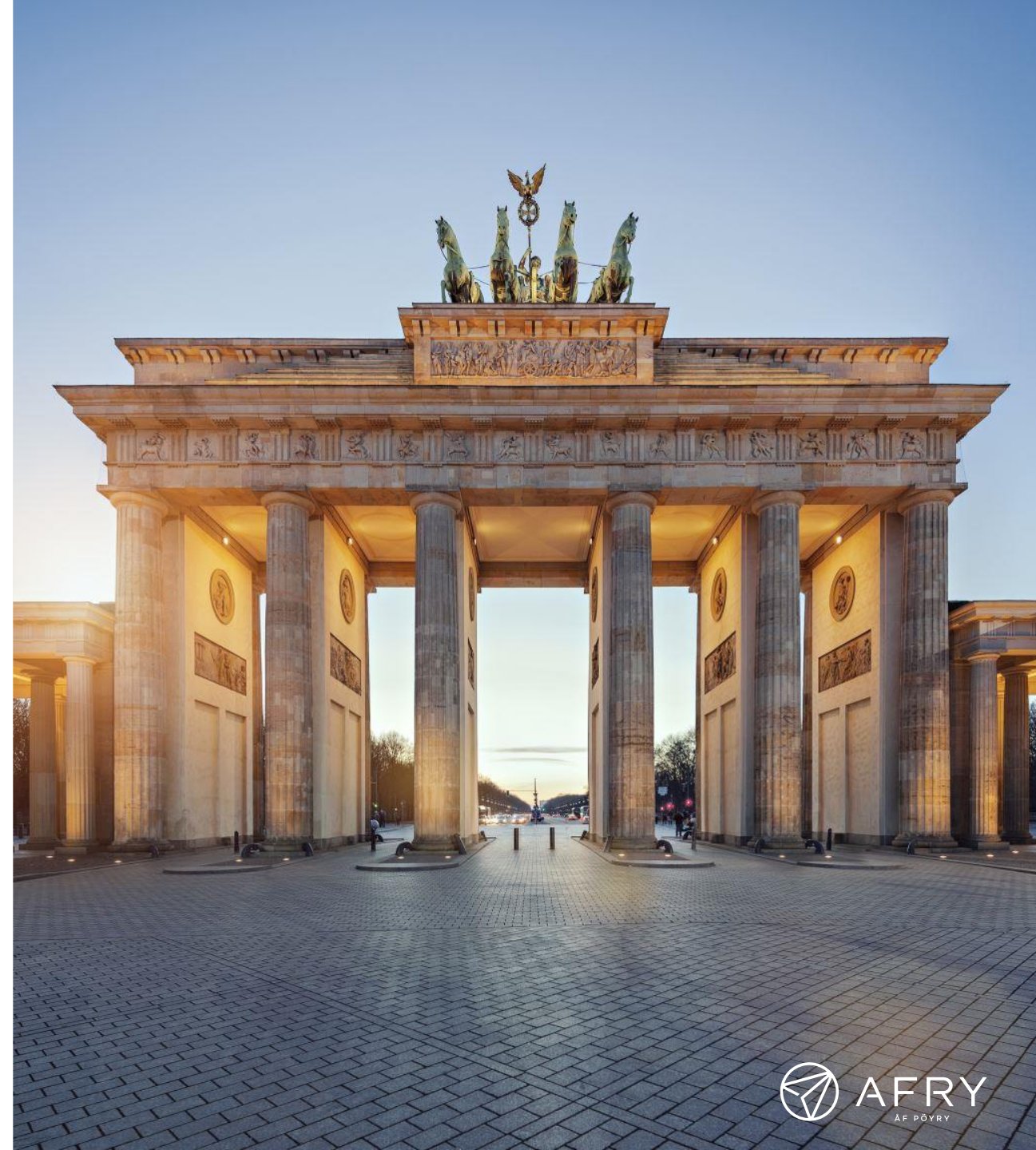
The German **H2Global programme** is a funding programme for hydrogen imports where an intermediary company will agree to long-term import contracts and then sells the hydrogen to industries. Both off-take and supply are based on auctions where the price difference is minimised and ultimately compensated with public funding. Currently the programme is only open for third country imports, but tenders could be approved for EU-imports if consistent with EU state aid rules.

The Commission wants to implement the programme as a part of the European Hydrogen Bank to implement a joint importing scheme for hydrogen EU-wide.

1. Start of works has not taken place or equipment has not been ordered during the time of application. | 2. RRF totals ~700 billion EUR EU-wide.

Within the EU Germany has clear policy goals for imports

- Although part of the EU and aligned with the policies and regulations being developed for all member states, Germany has specific goals itself
- Germany has a policy to import 10GW of low carbon hydrogen by 2030 for use in industry, increasing to 80GW by 2040
- Through the H2 Global Instrument there is tacit support for accelerating investments in green hydrogen and derivatives projects
- HINT.CO has off the back of this launched an auction that will also procure green ammonia, green methanol and green SAF
- This represents a near term opportunity for Ireland should there be sufficient resource and infrastructure in place to get a green product to a port in Germany, Netherlands or Belgium to satisfy the HINT.CO auction



Germany has a strong focus on importing low-carbon hydrogen, particularly from the MENA region, but strict EU regulations may make this difficult

Macro indicators

Credit rating	AAA
GDP growth (2024-2027)	1.5%
2022 primary energy consumption (TWh)	3,511
2021 hydrogen demand (mt)	1.5
2022 Renewable penetration (%)	37%
2022 Industrial power tariff	\$171/MWh
Electricity market structure	Zonal

Incentive scheme

- \$7.7b hydrogen strategy in 2020 for R&D, infrastructure and international partnerships (i.e. Japan for FCVs)
- \$328m program to launch hydrogen refueling stations for FCVs
- Reduced tax rate on hydrogen fuel cells used in commercial vehicles
- \$274m – PtX Development Fund to promote hydrogen investments – KfW bank
- \$328m PtX Growth Fund to accelerate global market ramp-up and infrastructure low-carbon hydrogen – KfW bank
- European Union:
 - Green Deal Industrial Plan, EU – fixed premium to low-carbon hydrogen producers for 10 years funded under €38 b Innovation Fund
 - IPCEI Hy2Tech – \$5.9b public funding for 35 countries including Germany.
 - EU ETS certification – green hydrogen is 18gCO₂e/MJ

Hydrogen and decarbonisation targets

- Hydrogen production / end-use targets:
 - **40-75TWh low-carbon hydrogen by 2030, 10GW by 2040**
 - 1m FCVs by 2030, 400 refueling stations by 2040
 - Replace 20% fossil fuels with hydrogen in steel production by 2030
- Import / export targets:
 - Imports target of 10GW low-carbon hydrogen by 2030 and 80GW by 2040
- decarbonisation targets:
 - Reduce GHG emissions by 55% compared to 1990 levels by 2030 (88% by 2040)
 - 65% electricity from RES by 2030 and 80% by 2040.
 - 40% renewables in final energy consumption by 2030
 - Net zero by 2045

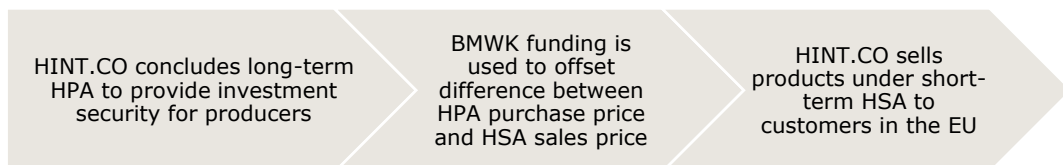
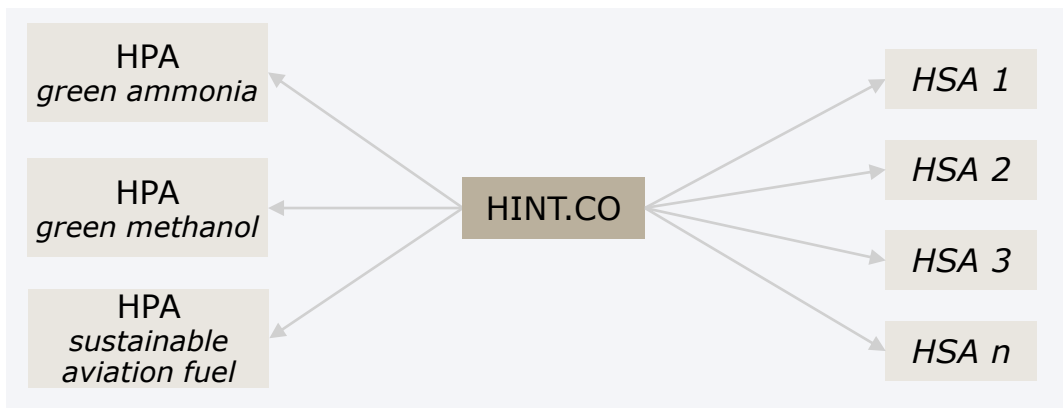
Key policies and projects

- Key policymaking and regulatory bodies
 - Ministry of Economic Affairs and Energy – National Hydrogen Strategy draft update, 2023
 - Ministry of Economic Affairs and Energy – National Hydrogen Strategy, 2020
 - European Union REDII (delegated acts on RFNBOs and greenhouse gas emission reduction)
- Key projects / players
 - H2Rivers
 - Hyways for future
 - HyBayern
 - Norddeutsches Reallabor
 - eFarm – GP Joule

Sources: Credit Rating: S&P; GDP growth: IMF WEO; Primary energy consumption and renewable penetration: BP; Hydrogen demand; Midrex, Global Data, AFRY Analysis; Industrial power tariff: AFRY analysis | Notes: RFNBO – Renewable fuel from non-biological origin, MENA – Middle East and North Africa, RED – Renewable Energy Directive, ETS – Emissions Trading System

HINT.CO has launched 3 'Expression of Interest' to procure green ammonia, green methanol and green sustainable aviation fuel

CONTRACTUAL LANDSCAPE



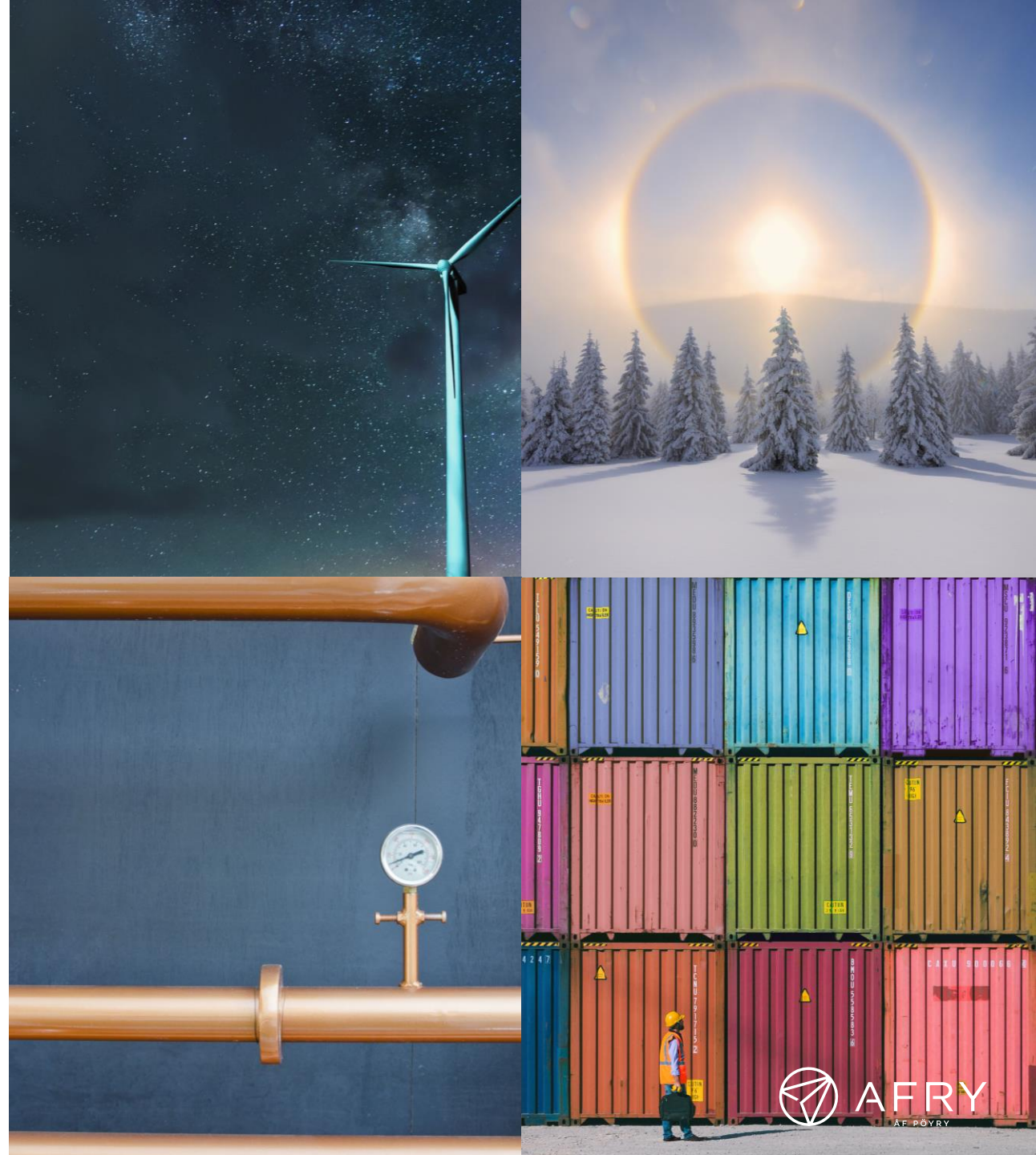
COMMERCIAL KEY POINTS

- **Parties:** HINT.CO and winning bidder as determined by tender
- **Products:** green ammonia, green methanol, sustainable aviation fuel (one HPA for each product)
- **Term:** 10 years (1 January 2024 – 31 December 2033)
- **Quantity:** Determined by annual funding amount and agreed price
- **Price:** Includes product cost, transport charge, logistics & dispatch and import duty
- **Delivery:** A port in Germany, Belgium or the Netherlands at agreed intervals
- **“Take or pay”:** HINT.CO will assume commercial risk if the products cannot be sold at competitive prices
- **Product quality:** Determined by technical product specifications, additional product specifications and additional sustainability requirements
- **Contractual safeguards:** Performance bond, penalty payments, termination rights in favour of HINT.CO

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4. Domestic hydrogen demand

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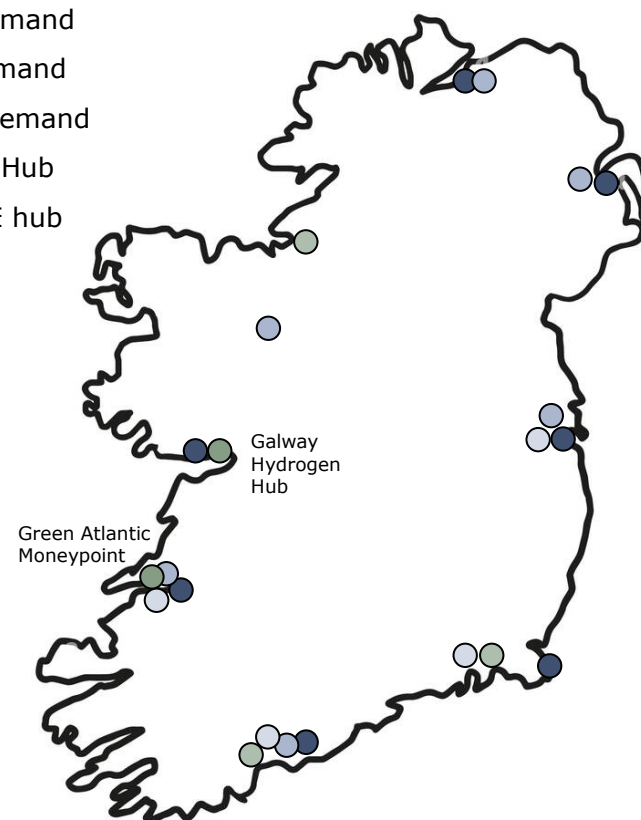
From a very small existing demand Ireland will have to scale up end-uses significantly to develop a domestic hydrogen economy

IRELAND

- Ireland has little to no existing domestic production of hydrogen, with the largest source of hydrogen being produced at the Whitegate refinery in Cork
- What little demand does exist is used in the food, pharmaceutical and semiconductor industries
- As such this demand is concentrated in 5 main clusters with an additional 2 in Northern Ireland
- Derivatives of hydrogen are used in additional processes in Ireland with no current production domestically
- Ammonia is consumed in fertiliser production in Ireland, but all demand is met by imports
- Ireland will need to create and scale up new hydrogen demand uses which currently do not exist at a significant level
- This could include derivatives such as ammonia, methanol and Sustainable Aviation Fuels (SAF)

PLANNED AND POTENTIAL HUBS, AND DEMAND CENTRES

- Maritime demand
- Aviation demand
- Industrial Demand
- Planned RE Hub
- Potential RE hub



DOMESTIC HYDROGEN DEMAND

Ireland has prioritised a number of areas in the hydrogen strategy

- In terms of use cases the Ireland hydrogen strategy has set out the priority areas it sees as being drivers of increased demand in Ireland:
 - Flexible Power Generation and Long Duration Energy Storage
 - Integrated Energy Parks for Large Energy Users
 - Industrial Heat and Processing/Feedstock
 - Aviation and Maritime fuel
- Other key areas where hydrogen could be used is where it would displace existing fossil fuel use such as the pharmaceutical industry and cement industry
- Low temperature heat and processes are most likely able to be satisfied by electrical solutions and it is not proposed that hydrogen be used for space heating
- Road and rail transport is likely to be all BEV, though there may be some small niche applications for heavy trucking, large passenger vehicles and non-road heavy vehicles – this demand is expected to be tiny



Projected domestic green hydrogen demand ROI, demand for use in power is low and is predominantly from other sectors

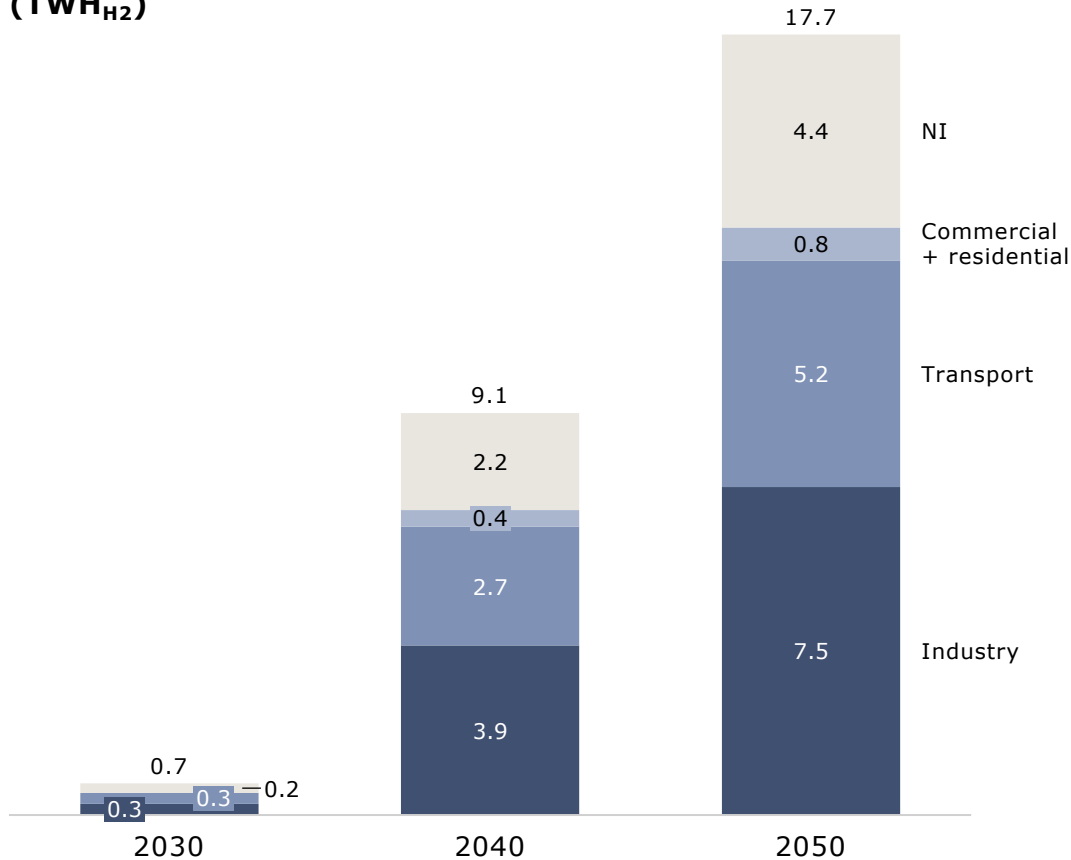
COMMENTARY

- AFRY has modelled the domestic demand for Ireland which is comparable to the modelled outcomes from the Domestic Net Zero hydrogen strategy
- In addition to the base domestic modelled demand, AFRY has built modelled scenarios for what additional demand could be created and that growth in Ireland
- We have focussed on Ammonia, methanol and SAF as the largest credible use cases of additional hydrogen in Ireland
- Taken together this would mean Total hydrogen demand in Ireland of 3.79TWh in 2030, 16.53TWh in 2040 and 32.05TWh in 2050

		Domestic Demand (TWH_H2)	2030	2040	2050
Modelled Demand (WS1)	Power		0.00	0.00	0.25
	Commercial and Residential		0.00	0.40	0.80
	Transport (Road and Rail)		0.30	2.7	5.20
	Industry		0.30	3.90	7.50
Subtotal			0.60	7.0	13.75
Other Potential Domestic demand	Aviation (eSAFs)		0.55	6.00	13.50
	Maritime (Hydrogen-based fuels)		0.065	0.55	1.30
	Other potential non-energy uses (Fertilisers)		2.45	2.98	3.50
Total			3.79	16.53	32.05

Non-power demand growth in Ireland is dominated by industry with transport and Northern Irish demand also showing growth

SEM DOMESTIC NON-POWER HYDROGEN DEMAND (TWH_{H2})



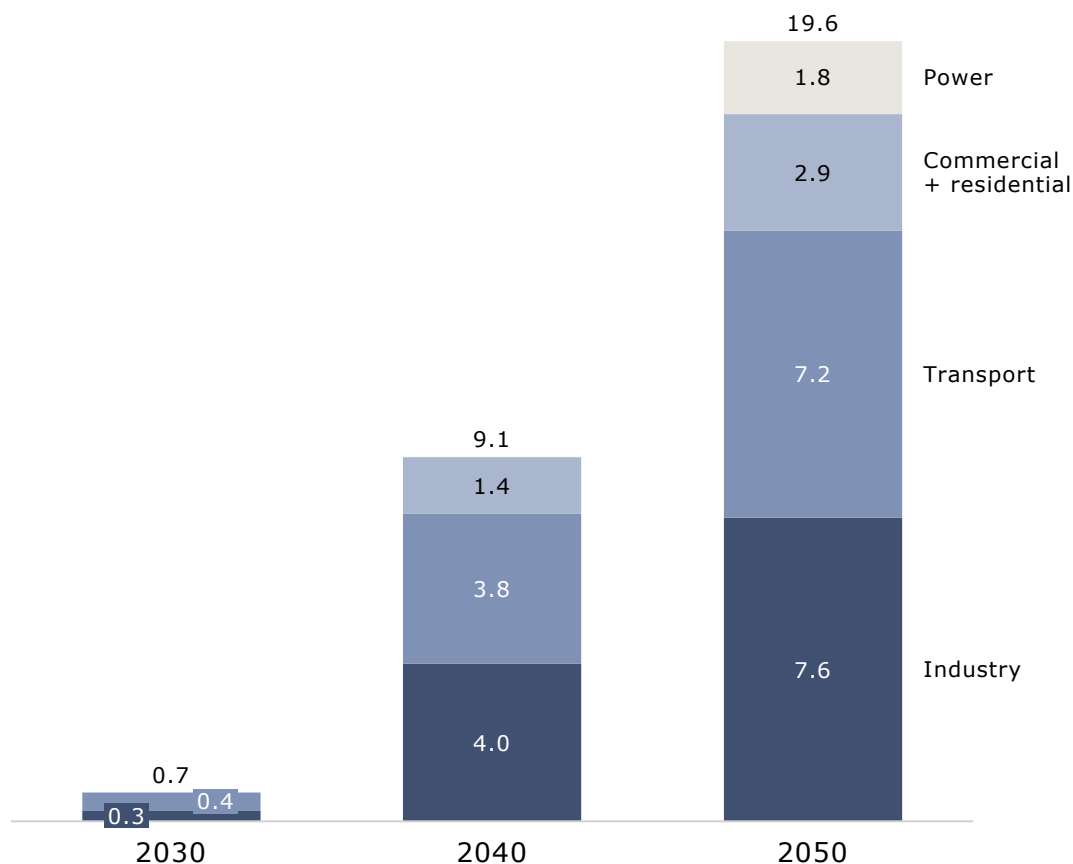
OVERVIEW

- Industrial demand is expected to be the switching of fossil based fuels to hydrogen in high temperature heat and the use of hydrogen in processes
- The growth in Northern Ireland is significant but has been grouped in these graphs as it may be supplied externally
- Transport is the second biggest sector but it is important to note that this demand is passenger and good vehicles and does not include marine and aviation
- The expectation is that the majority of this transport demand will be for heavy trucks and buses with limited demand in other types of vehicle
- Overall domestic demand for hydrogen is low and stays that way up to 2030
- From 2030 onwards it is expected that there will be significant growth as hydrogen is available at scale and can be transported by pipe
- Although there is a significant uptick in demand in 2040 and up to 2050, this demand is still small in global standards (c. 0.5Mt)
- In all scenarios it is assumed there is no constraint on storage of hydrogen

DOMESTIC HYDROGEN DEMAND

Including power demand does not change the picture for demand growth as the ORE with batteries is sufficient to meet demand

SEM DOMESTIC HYDROGEN DEMAND (TWH_{H2})



DISCUSSION

- Including the power based use of hydrogen does little to alter the picture for hydrogen demand across the scenario years
- Power sector demand is relatively low - This is because in 'normal' weather conditions (note that the modelling in this study has investigated the system under 5 representative weather patterns), there is sufficient renewables generation / energy storage / interconnection to address the vast bulk of demand.
- Thermal generation is only required when the system is very tight (e.g. when demand is high and renewables output is low in the SEM, GB and France leading to relatively low imports).
- System stability is provided by a range of low carbon technologies, with synchronous condensers providing inertia, system strength and reactive power, STATCOMs and shunt reactors providing reactive power capability and 6.5GW of sub 6hr Li-ion batteries providing reserves and short-duration ramping capacity.
- Whilst it is important to have some power capability for hydrogen in the system it is not going to be in sufficient volumes to change the overall demand growth picture

The potential for Irish green hydrogen derivatives is mainly in Ammonia but SAF and Methanol could play a role

Comments	Positives	Risks
<p>Ammonia</p> <ul style="list-style-type: none"> Hydrogen required for ammonia is produced using fossil fuels, the price of which has resulted in ammonia price volatility. Production is expected to grow by 40% by 2050 in response to demand increases driven by economic and population growth Ireland currently does not produce ammonia, importing all requirements. 	<ul style="list-style-type: none"> Prospect to supply domestic use and export, price parity with non-green ammonia production potential by 2030. Domestic demand could consume 2.45 TWh_{H2} in 2030 International demand growing, and retiring European plant imminent Other potential end users exist outside of fertilisers, including as an energy carrier and in maritime fueling Most mature and lowest cost option for long distance trade of H₂ - 20 Mt of ammonia are already traded internationally each year with 120 dedicated terminals 	<ul style="list-style-type: none"> Scale of domestic market, and price of green hydrogen, export potential as carrier (cracking prices etc.) Competition with non-European exporters
<p>eSAF</p> <ul style="list-style-type: none"> Use of H₂ directly in aviation in 2030 is predicted to be 0.5 Mt (1 Mt eSAF) including e-kerosene and hydrogenation of biofuels ReFuelEU Aviation targets could generate a large market for hydrogen – 35-70% of fuel needs National Hydrogen Strategy predicts a demand for eSAF of 0.79-1.58 Mt by 2050 (13-26TWh_{H2}) GB mandated 10% SAF by 2030 	<ul style="list-style-type: none"> EU targets and Irish demand predictions would indicate a growing strong market for eSAFs using Green Hydrogen. Can make use of captured CO₂ 	<ul style="list-style-type: none"> Cost of eSAF is much greater than conventional jet fuel, with cost parity predictions post 2040

Emerging sectors such as steel, glass and ceramics are likely to be non-starters due to the need for scale and an existing supply chain

Comments	Positives	Risks
<p>Methanol</p> <ul style="list-style-type: none"> Existing industry using H₂ (chemical feedstock and transportation fuel) 30% of industrial hydrogen use is in methanol production, 85% of which is used as a chemical feedstock. Global demand for methanol has experienced 3.3% annual growth since 2018 reaching 106 Mt in 2022, with forecasts of 130 Mt in 2050. Methanol is used in the production of biodiesel, a Dept. of Transport biofuels report 2022 estimates a demand for biodiesel (or HVO) of 570-730m litres in 2030 (5-6.4 MWh). FuelEU Maritime target a 2% use of RFNBOs in the maritime sector. Port of Foynes Strategic Review 2040 has initial plans for e-methanol production and storage 	<ul style="list-style-type: none"> There is an existing market for methanol as well as emerging end-use industries (maritime transport). Can make use of captured CO₂. Methanol can be used to produce biodiesel for use in transport and agricultural sectors 	<ul style="list-style-type: none"> Cost of green hydrogen methanol parity with fossil fuel generated H₂ not expected until 2045
<p>Steel</p> <ul style="list-style-type: none"> 10% of industrial H₂ use is currently in the Iron and Steel subsector, which relies on hydrogen produced from fossil fuels Using green hydrogen in steel production can reduce the energy requirement and decarbonise the process (DRI). By moving from coal use to green hydrogen CO₂ emissions for one ton of steel can be reduced from 1.85 tons to 0.08. Global demand for steel is expected to reach 2 billion tons by 2030, with demand in the main sales areas for European steel to reach 395 Mt (including EU West). 		<ul style="list-style-type: none"> Very small industry in Ireland, would require a large domestic industry to be created to make use of domestic hydrogen. Potential sales area for domestic green hydrogen have established industries (Germany, France) Costs of using green hydrogen prohibitive currently – 1 ton of steel 33% more expensive

The technical viability of hydrogen in different sectors has been proven, but competition from alternatives is high

- Transition to the use of low carbon hydrogen is not a technical issue for many industries that currently use Hydrogen as a feedstock
- The main differentiator is on demand and price; for sectors that have little alternatives such as fertilisers, methanol and refining there is always going to be demand coupled with expected expansion (or contraction) of those sectors
- Where there is an alternative such as for the steel, glass, ceramics, cement, aviation and maritime sectors, the cost of green hydrogen is the major hindering factor
- The expectation is that electricity will win in every competition it can and the use of hydrogen will therefore be on different economic ranking criteria (for example flexibility or resilience)
- This extends to transport where direct substitution of alternative fuels may displace demand that otherwise could be filled by hydrogen and where batteries are not efficient
- The future of aviation and shipping fuels will be instrumental in driving transport demand which could have a big future for hydrogen (and its derivatives) or not
- Given Irelands location as a potential bunkering location for shipping or a stopover point for Transatlantic flights this could be a huge opportunity but it is by no means certain

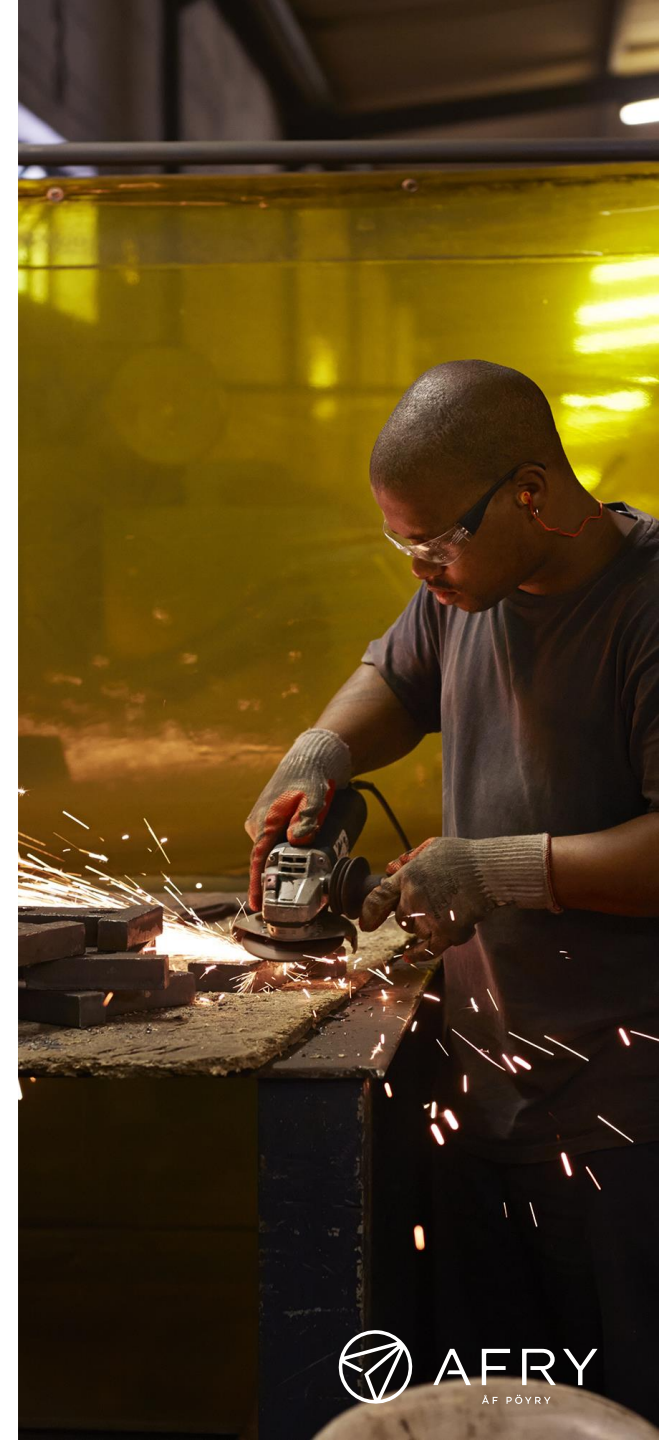
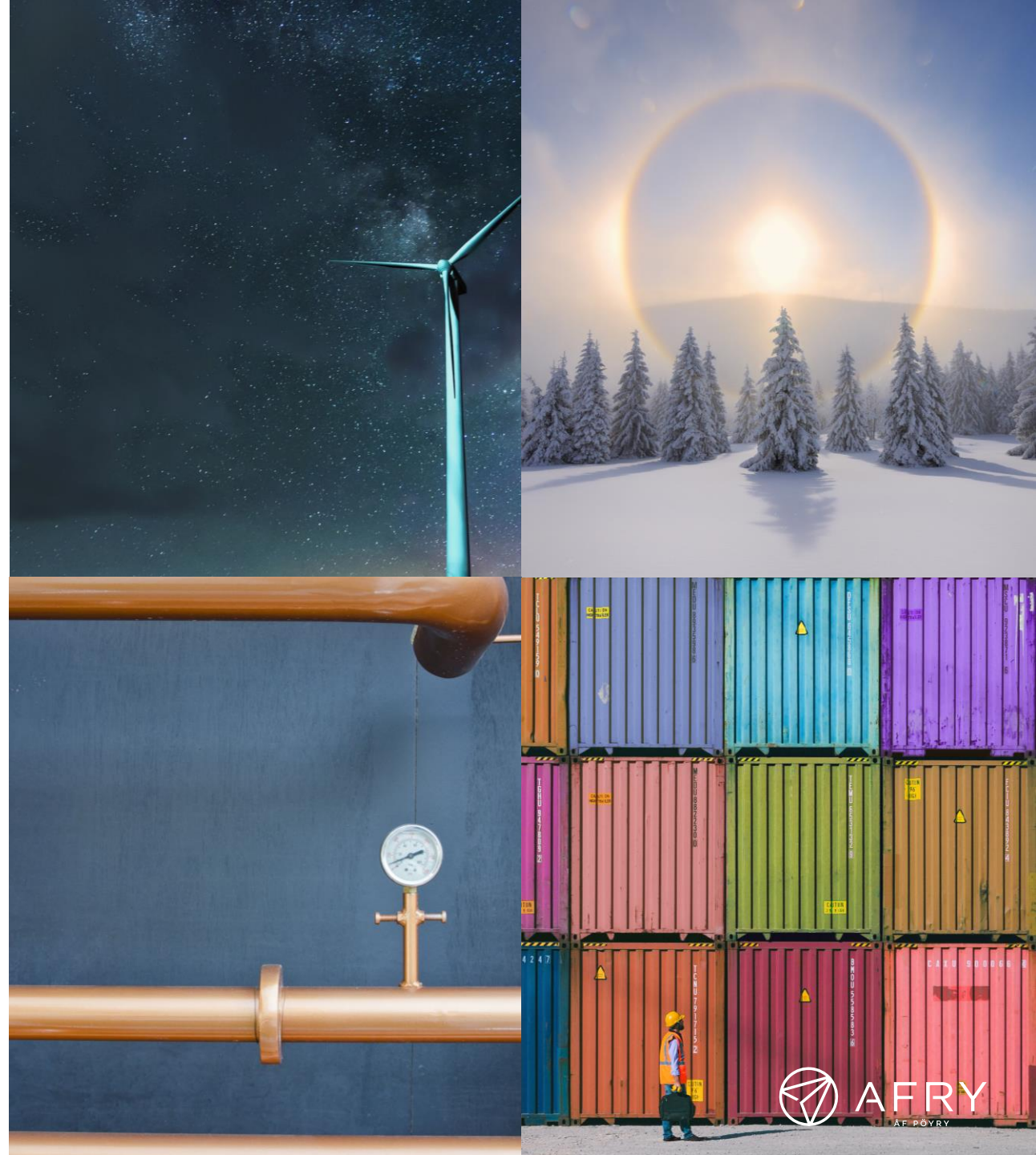


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5. European hydrogen demand

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Hydrogen strategies across Europe and the world, are driving the demand for low carbon hydrogen and ammonia

Ireland Hydrogen Strategy

- Deliver 2 GW of dedicated offshore generation - 2030
- Industry and Transport are target sectors

UK 10 point plan

- £4Bn investment required
- CCS supported with £1Bn in 4 clusters
- 10GW target for low carbon hydrogen production

France Hydrogen Strategy

- Transport and industry are key sectors
- > €7Bn in funding to 2030
- 6.5GW electrolyser capacity by 2030
- Plans to build 2 pink hydrogen mega factories by 2030

Spain Hydrogen Strategy

- 4GW electrolyser capacity by 2030
- €8.9Bn in funding
- 2030 target for 25% share of industry demand

Portugal Hydrogen Strategy

- 2GW electrolyser capacity by 2030
- €7Bn in funding
- Sines 1GW H2 project

Denmark PtX Strategy

- Focus on e-fuels
- 4-6 GW of electrolyser capacity 2030
- Export ambitions

Norway Hydrogen Strategy

- Maritime transport is the key focus
- Low-carbon (SMR+CCS) and renewable hydrogen are supported

Finland Hydrogen Roadmap

- Part of the national energy and climate strategy - use of low-carbon hydrogen in synthetic fuels, steel, logistics

Netherlands Klimaatakkoord

- 4 GW electrolyser capacity by 2030
- €35Mn per annum
- Green and Blue H2

Belgium Hydrogen Strategy

- Belgium as an import/transit hub
- 20TWh imports by 2030

Poland Hydrogen Strategy

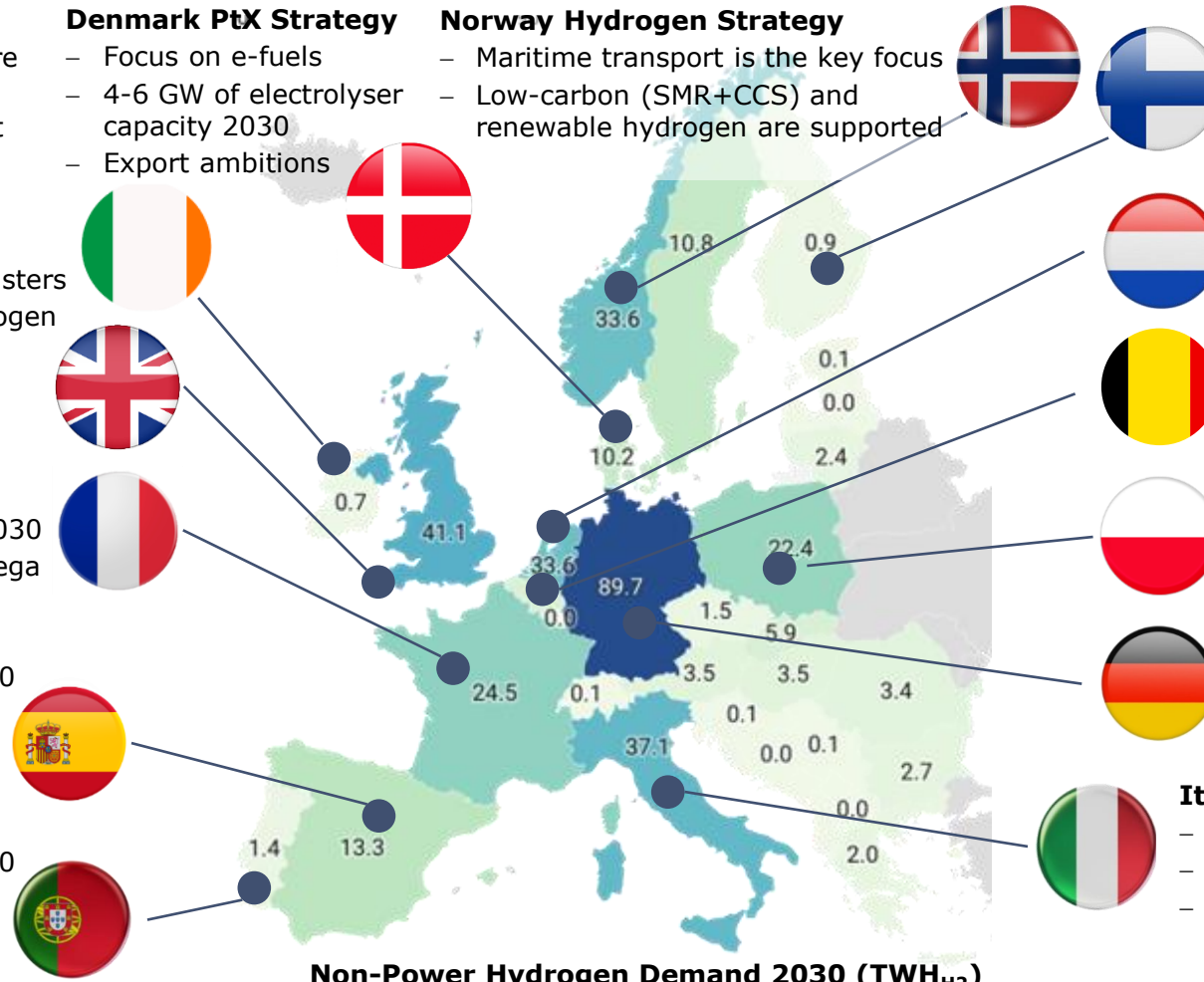
- 2 GW electrolyser capacity by 2030
- 1 Billion PLN in funding

Germany Hydrogen Strategy

- 5 GW electrolyser capacity by 2030
- > €9Bn in funding to 2026
- Carbon CfD in development

Italy Hydrogen Strategy

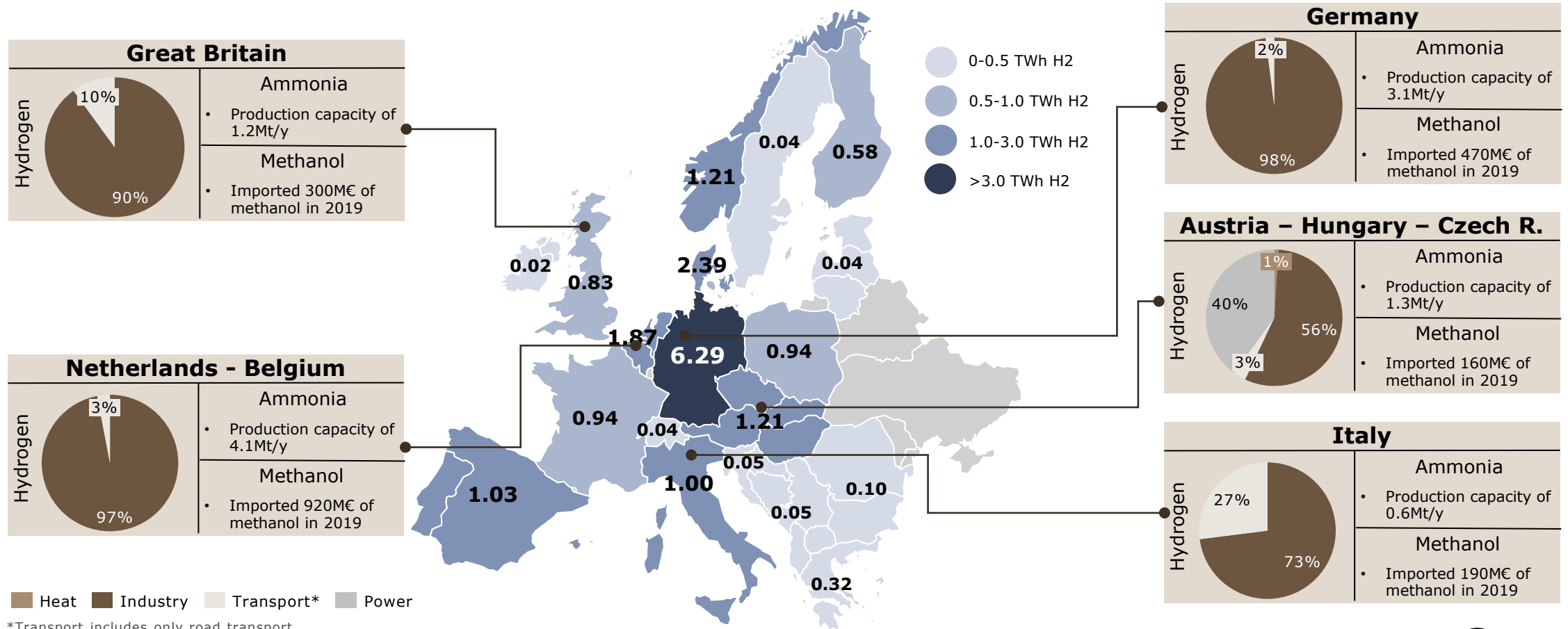
- 5 GW electrolyser capacity by 2030
- €5 Bn in funding
- Target of 2% penetration on final energy demand



Non-Power Hydrogen Demand 2030 (TWh_{H2})

Industrial processes account for most of the hydrogen demand in Europe, while Germany is the largest European consumer of hydrogen

2025 HYDROGEN DEMAND MAP IN EUROPE (TWh)



The key industrial users of hydrogen are fertilisers and refining

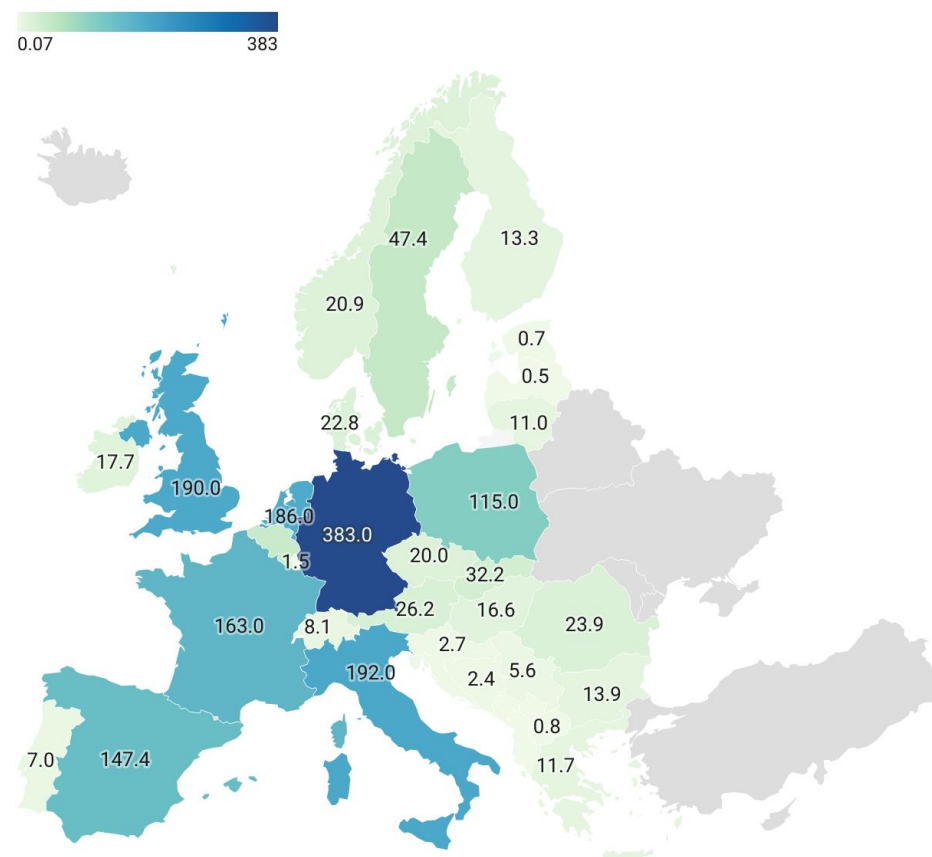
- Top 5 demand centres for hydrogen in Europe are:
 - Ammonia/Fertilisers
 - Refining
 - Methanol
 - Energy/Industrial heat/Process Feedstock
 - Other chemicals/Food
- Of these the most credible opportunity for Ireland could be to replace current imports of ammonia used in fertilisers with domestic supply and also produce excess for export
- New industry that could make use of hydrogen is usually transport related with either marine fuels (of which ammonia and methanol are leading candidates) and Esaf – both have EU targets associated with them that could attract subsidy and investment
- Other industries, such as steel production, where green H₂ could be used for decarbonisation, are unlikely to be active in Ireland due to the slim margins and massive scale required to be competitive
- That is not to say that a niche steel, ceramics and glass industry based on hydrogen is not possible but would need to think carefully about products and markets

Hydrogen demand in Europe is forecast to grow, focussed in NW Europe where imported hydrogen will be required to supplement production

ANALYSIS

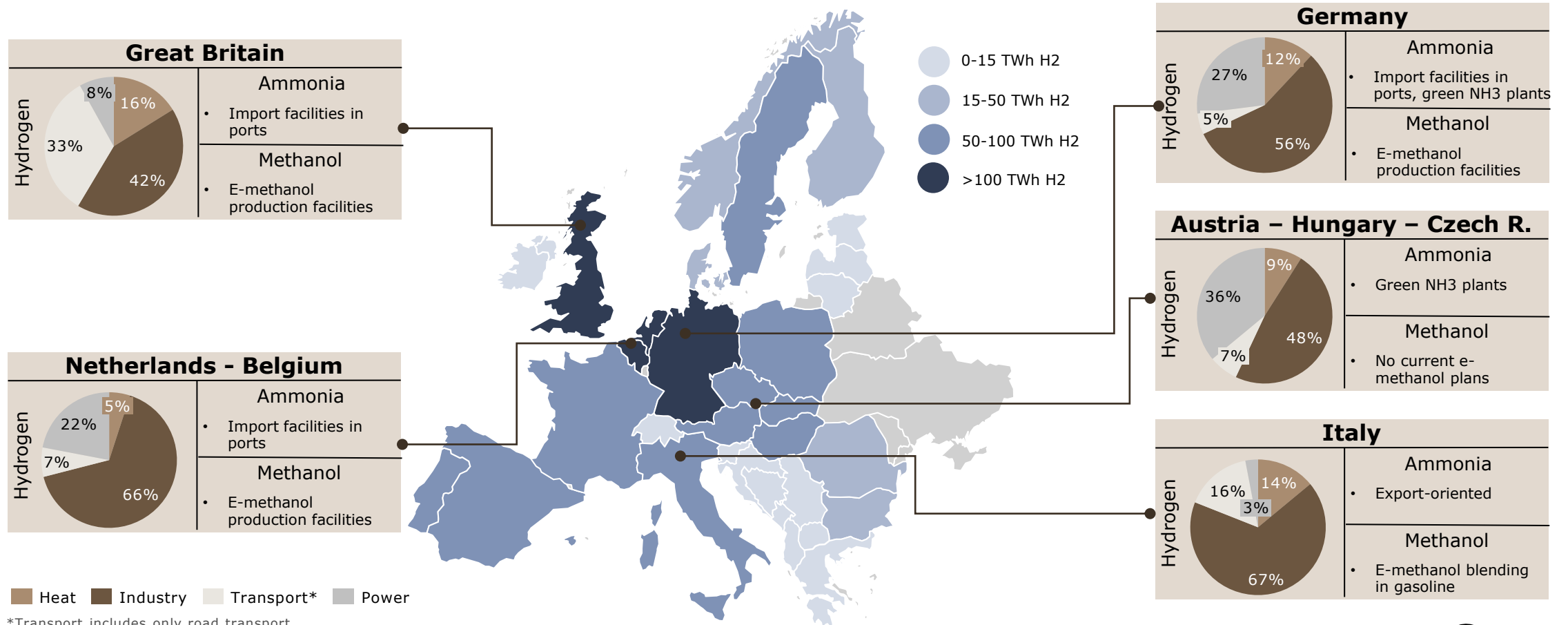
- Increased demand across Europe is forecast reflecting its use in energy security, and in decarbonising targeted sectors including industry and transport.
- EU energy autonomy and geographical diversification of energy supplies have become top priorities and green hydrogen has been recognised as playing a crucial role in this
- National Hydrogen Strategies across Europe, including Germany and France, have recognised that domestic markets will not be sufficient to meet demand and that a large proportion will need to be covered by imports
- Demand for grey hydrogen currently exists in Europe in industries prime for transition to Green Hydrogen. The Netherland consumes 1.3 Mt of grey hydrogen per annum and Germany consumes 1.7 Mt. Most of this is used as a feedstock in the refining industry
- Non-power European demand in 2050 could reach 1730 TWh_{H2}

NON-POWER HYDROGEN DEMAND 2050 (TWh_{H2})



Hydrogen demand shows significant growth across Europe by 2050 especially in the power sector which holds a 15% share in the total demand

2050 HYDROGEN DEMAND MAP IN EUROPE (TWh)



Projected European demand shows a big role for hydrogen in a range of industrial processes including steel and ammonia but also power

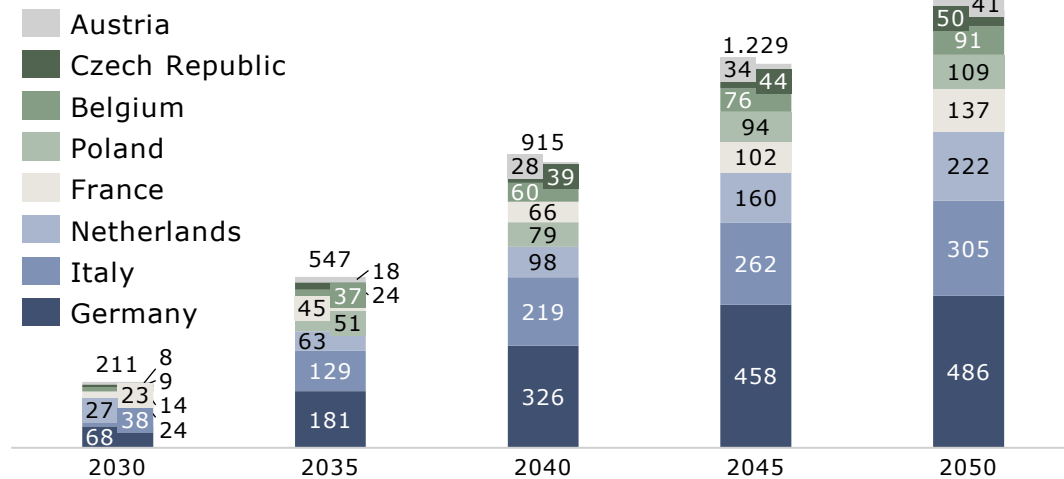
COMMENTARY

- Fuel production at refineries is predicated to be the largest consumer of hydrogen, the use of hydrogen includes hydrogenation of fossil fuels, upgrading to bio kerosene, synthetic kerosene and fuels for HVCs.
- Total projected demand in 2050 for the fuel sector is 691 TWh, with 291 TWh of that used mostly to produce ethylene and propylene, which are used to produce plastics, and a range of other products
- Industrial heat processes – 239 TWh_{H2} - Industrial process heat is defined as thermal energy used directly in the preparation or treatment of materials used to produce manufactured goods and does not include spatial heating – 30% of medium heat needs and 50% of high heat needs assumed for 2050

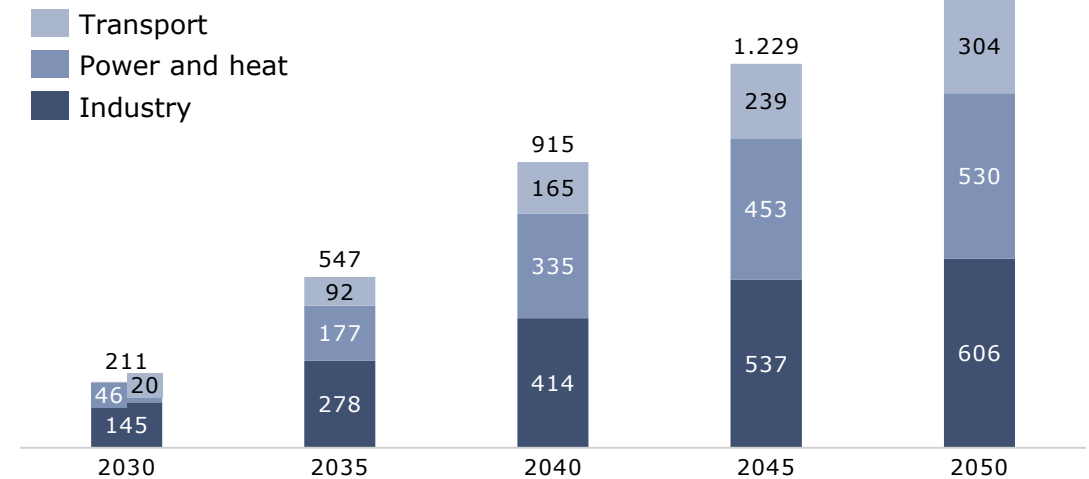
		Domestic Demand (TWH_H2)	2030	2040	2050
Modelled Demand (WS1)	Power		12	301	626
	Commercial and Residential		0.1866	120	239
	Transport (Road and Rail)		13.65	107.8	199.2
	Industry		305	838.5	1292.6
Subtotal			331	1367	2357
Other Potential Domestic demand	Aviation (eSAFs)		0	74.8	226
	Maritime (Hydrogen-based fuels)		?	?	?
	Other potential non-energy uses (Steel/Fertilisers)		57.04	102.96	156.11
Total			388	1545	2740

AFRY projects H₂ demand to substantially increase, driven by H₂ use in industry, power and heat sectors, with Germany being a central demand hub

LOW-CARBON H₂ DEMAND FORECAST BY GEOGRAPHY 2021-2050 (TWH¹)



LOW-CARBON H₂ DEMAND FORECAST BY SECTOR IN SAME GEOGRAPHY 2021-2050 (TWH)



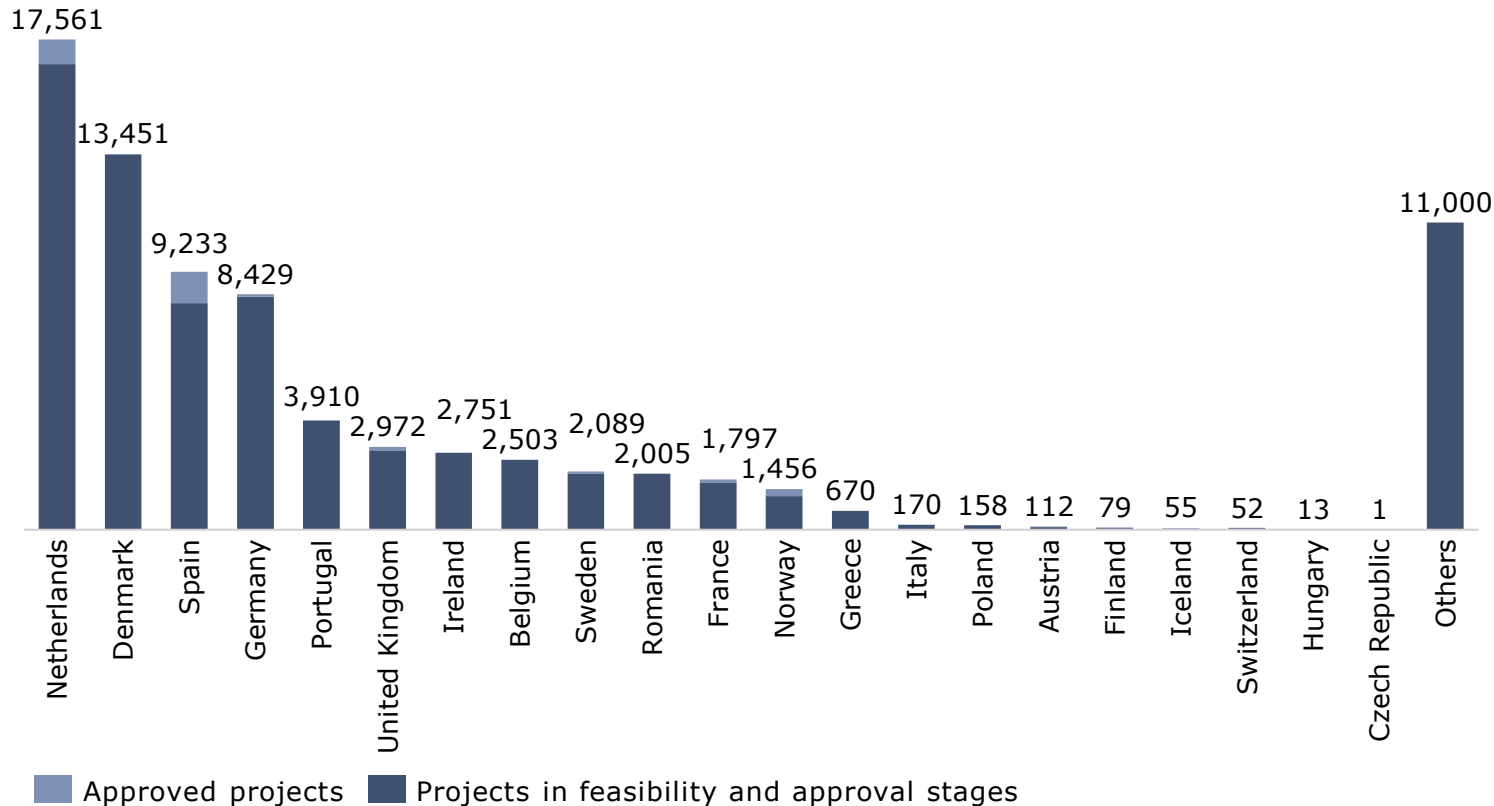
- AFRY expects H₂ to cover a large share of final energy demand in the selected geographies with Germany playing a central role
- Germany's accelerated decarbonisation path pushes H₂ demand to increase with a steep slope in the early 2030s, to then settle with a less aggressive growth rate from 2045 onwards
- Germany came first with a H₂ strategy and has the highest amount of non-merchant electrolyser capacities out to 2040

- H₂ demand is mostly driven by the necessity to decarbonize the industrial sector, that will already show a relatively high demand for H₂ in 2030 (145 TWh)
- Demand for H₂ in power and heat sector will mainly pick up starting in the 2030s, settling at 530 TWh in 2050
- Demand for transportation will grow at a stable pace to reach 304 TWh by 2050

1. Data in LHV | Sources: AFRY analysis for German demand; TYNDP 2022 scenario for other countries

The Netherlands currently plans for the deployment of most European green hydrogen production capacities, followed by Denmark, Spain and Germany

ANNOUNCED ELECTROLYSIS PROJECTS BY CAPACITY (MW¹)



COMMENTS

- The total of the announced projects in Europe amounts to around 80 GW of installed electrolyser capacity, although today only 3 GW have been approved
- Taking into account all announced projects, the Netherlands and Denmark account for the highest electrolyser capacity, with 17.6 and 13.4 GW respectively. Spain and Germany follow closely
- Spain is leading the way with the highest number of approved projects (1.1 GW), closely followed by the Netherlands (0.9 GW)
- AFRY expects only a part of the announced projects to be approved in the next years

1. MW = Megawatt | Sources: AFRY analysis; GlobalData (May 2022)

EUROPEAN HYDROGEN DEMAND

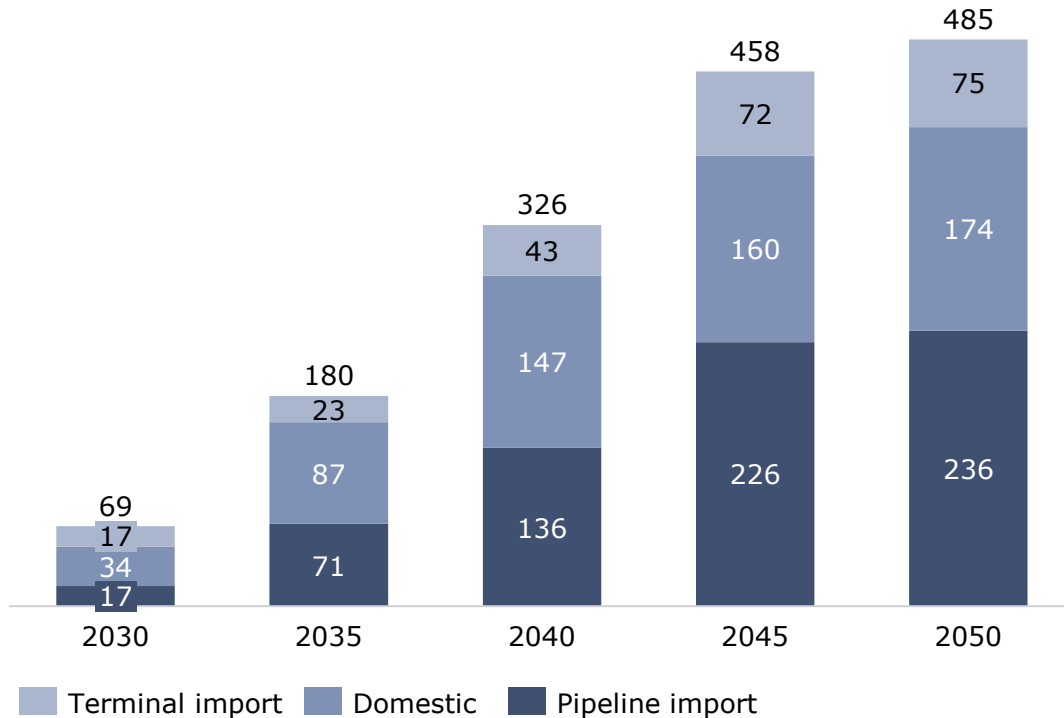
The indication is that Germany will have a gap in domestic production versus demand though there is disagreement on what that volume will be

	Electricity demand 2045 in TWh	Hydrogen demand 2045 in TWh	Hydrogen supply shares ■ = imported	Types of nationally produced hydrogen	Sources of imported hydrogen	Target year for climate neutrality
Dena	829	458	85%	Only green	Europe, MENA ² , South America, Australia	'45
Agora	899	265	64%	Only green	Europe and other regions with high RES potential	'45
TYNDP DE	820	444	66%	Only green	Europe, North Africa, Russia, Turkey and Ukraine ¹	'45
TYNDP GA	740	522	80%	Only green	Europe, North Africa, Russia, Turkey and Ukraine ¹	'45
BMWK Strom	882	363	51%	Only green	Europe, MENA ² & other regions with high RES potential	'45
BMWK H ₂	717	694	60%	Only green	Europe, MENA ² & other regions with high RES potential	'45

1: TYNDP data on import sources related to EU-27; 2: MENA = Middle East and North Africa | Source: AFRY analysis

German hydrogen supply will mainly rely on pipeline-based imports. National production contributes with 174 TWh or 36% in 2050

GERMAN H₂ SUPPLY DEVELOPMENT IN BASE CASE (TWH¹)



COMMENTS

- German hydrogen demand expectedly will not be met by national production only – imports via pipelines and terminals are needed as additional supply sources
- National production of low-carbon hydrogen is expected to increase from 34 TWh in 2030 to 174 TWh or 36% by 2050
- Pipeline- and terminal-based imports contribute the major share of supply from 2035 onwards
- Imports via ammonia and converted LNG terminals reach 75 TWh in 2050, contributing to a diversified supply mix
- Potentially lower-cost pipeline imports become most important supply option in the 2040s and enable a supply of 236 TWh or 50% by 2050

REGIONALISATION APPROACH

- AFRY regionalized national hydrogen production according to publicly announced capacities. Expected future capacity additions are allocated to energy-intensive industrial sites
- AFRY allocated imports to expected import terminal locations and pipeline interconnector points included in the FNB gas core network plans

1. Data in LHV | Sources: AFRY analysis; Wasserstoffatlas; Neuwirth et al (2022)

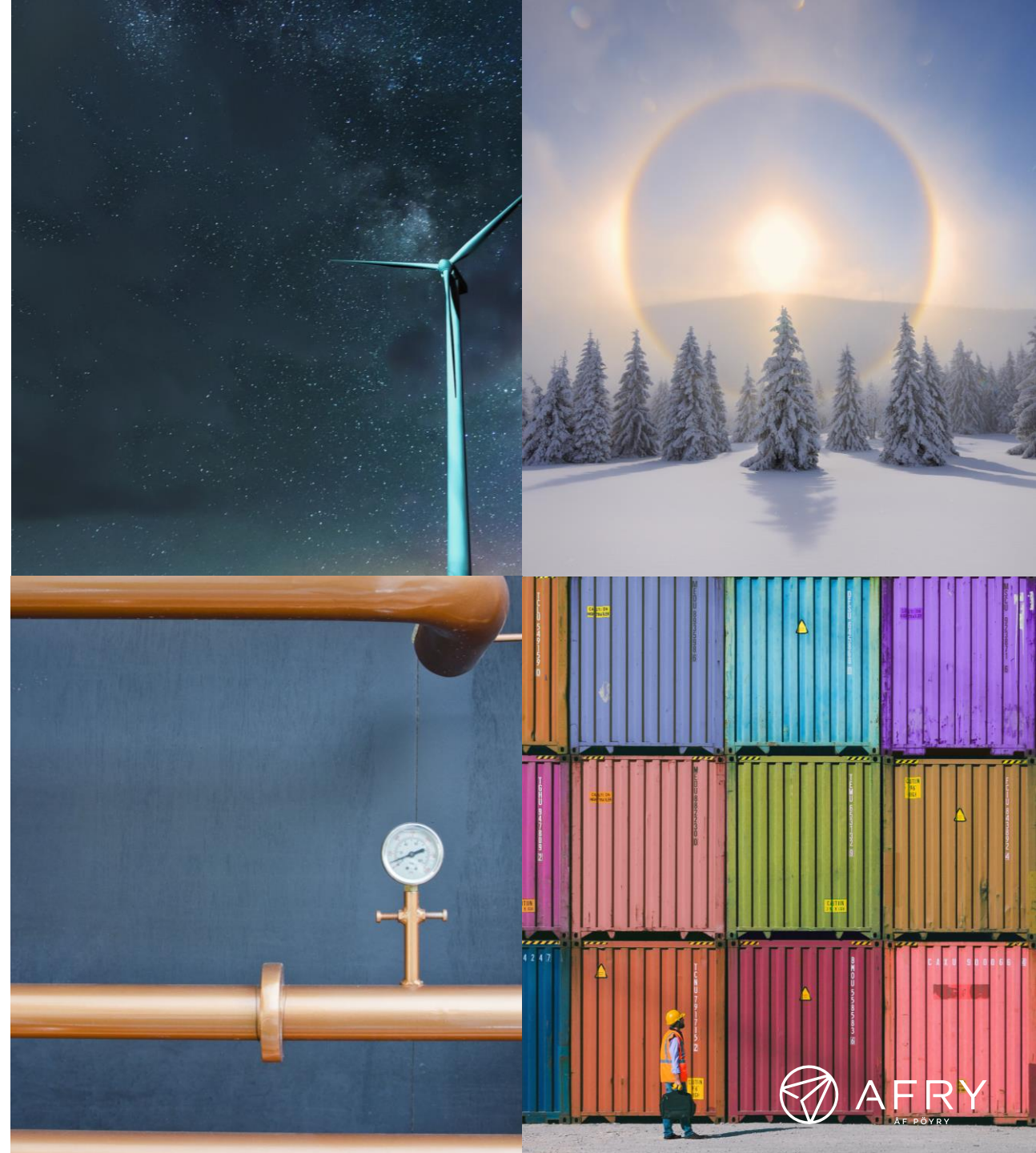
There is a clear demand in mainland Europe, particularly Germany that could be satisfied by Irish hydrogen exports

- It is clear that there will be significant demand for hydrogen in Europe across a range of demand sectors
- Based on current plans for domestic hydrogen production on mainland Europe there will be an overall gap in European demand that will need to be filled with imports
- By far the largest projected user of hydrogen will be Germany and it will be key to get any exports to that country by pipe or port
- Publicly available data suggest there will be a need for anything between 51-85% of total demand in Germany that will need to be satisfied by imports which amounts to at least 170TWh (5Mt) by 2040
- Assuming the same ratio, the supply gap in Germany could be 32TWh (1Mt) in 2030 and 224TWh (7.3Mt) in 2050
- Given the aggressive plans by the Netherlands and Denmark for electrolyser capacity as well as expected domestic growth, the opportunity for Ireland will be in moving fast and securing long term offtake agreements
- Key to how the opportunity unfolds will be the rate of infrastructure build out which will control how hydrogen flows around the continent or if Germany will be reliant on shipped hydrogen/ammonia

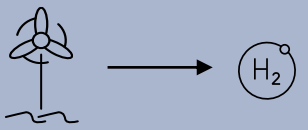

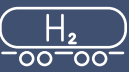
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6. Hydrogen Economics 54

- 6.1 Dedicated Hydrogen Production
- 6.2 Delivered Cost of Hydrogen
- 6.3 Economics of Curtailed Hydrogen

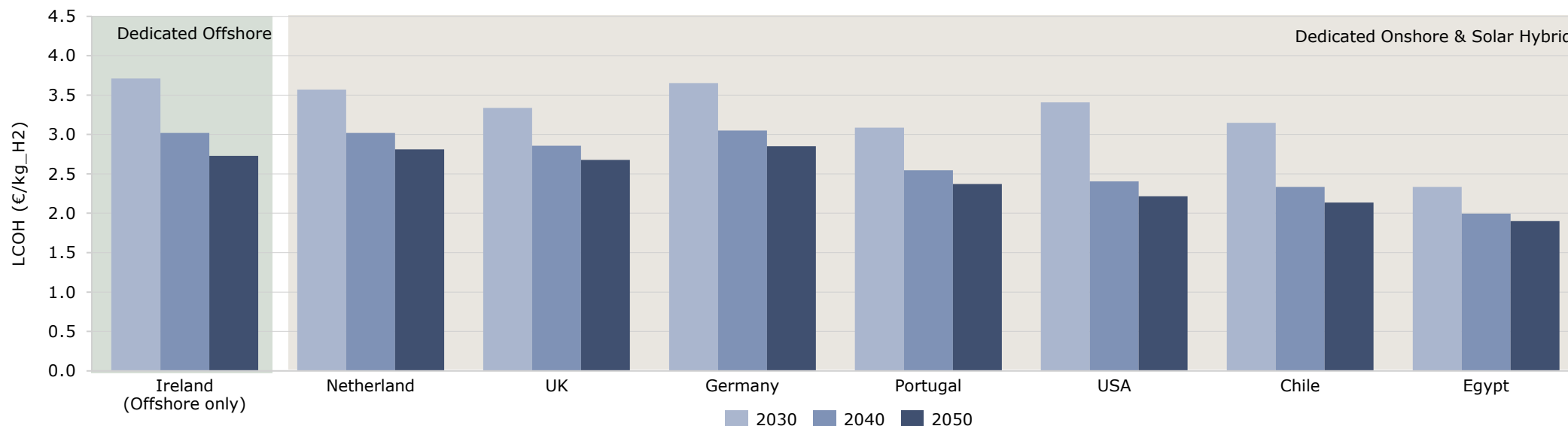


Logical assumptions have been made to analyse the economics of H2 production and export potential for Ireland

Calculation Area	Assumptions
 <p data-bbox="163 614 537 685">Levelised Cost of H2 from dedicated ORE</p>	<ul style="list-style-type: none"> - Levelised cost of production assumes optimised project configuration of generation, electrolyser and Salt Cavern Storage (SCS) capacities for a baseload supply of H2 - Key model inputs- such as Capex, Opex, and operating efficiencies – are based of expert insights and represent the industry viewpoint on future progression of the considered technologies
 <p data-bbox="163 906 537 978">Levelised Cost of H2 from Surplus ORE</p>	<ul style="list-style-type: none"> - Only surplus ORE contributions are assumed in this analysis, while surplus from all other generation technologies is dis-regarded - Surplus electricity is assumed available to electrolysers at the marginal operating cost for Offshore generation of 3.5 €/MWh_e - Electrolyser costs are optimised for low production costs and high output, while a constant levelised cost contribution of 0.5 €/kg_{H2} is assumed for SCS
 <p data-bbox="163 1199 537 1270">Levelised Cost of transporting H2</p>	<ul style="list-style-type: none"> - Transportation costs to Northwest Europe (NWE) are calculated by assuming France as the delivery point - H2 transport costs for using NH3 as an energy vector, considers – <ul style="list-style-type: none"> - NH3 synthesis and cracking costs - Green NH3 as the shipping fuel

Demand for H₂ imports will exist from Europe, Irish exports may struggle to compete as the cost of hydrogen is marginally greater than other countries

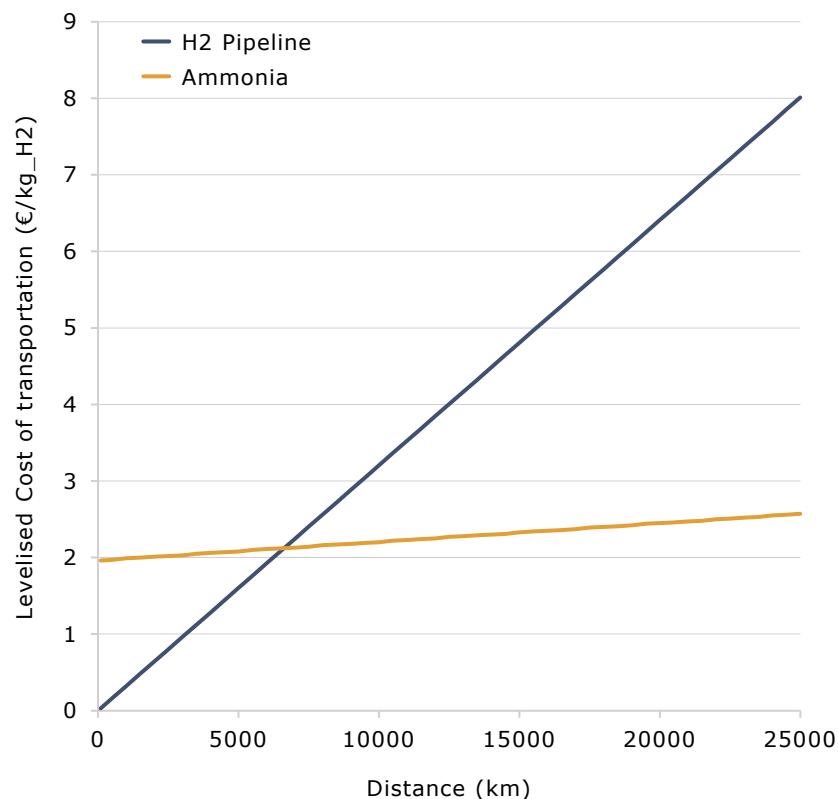
- Over the short term, LCOH in Ireland from off grid offshore remains to be the 2nd highest, in comparison to hybrid generation mix in competitive markets – curtailed generation is likely to improve this economic outlook
- Hybrid generation mix of Onshore and Solar yields the lowest LCOH among different technology types
- Transportation costs to demand hubs will be a key factor in shaping demand for green hydrogen for each exporter



Note: Levelised Cost of Hydrogen presented above represents a baseload scenario, comprising of electricity, electrolyser and salt cavern storage costs for an optimised capacity configuration.

Transportation costs further reduce the attractiveness of Irish Green Hydrogen, in comparison to local production in North-Western Europe

COST COMPARISON OF DIFFERENT MODES OF H2 TRANSPORTATION

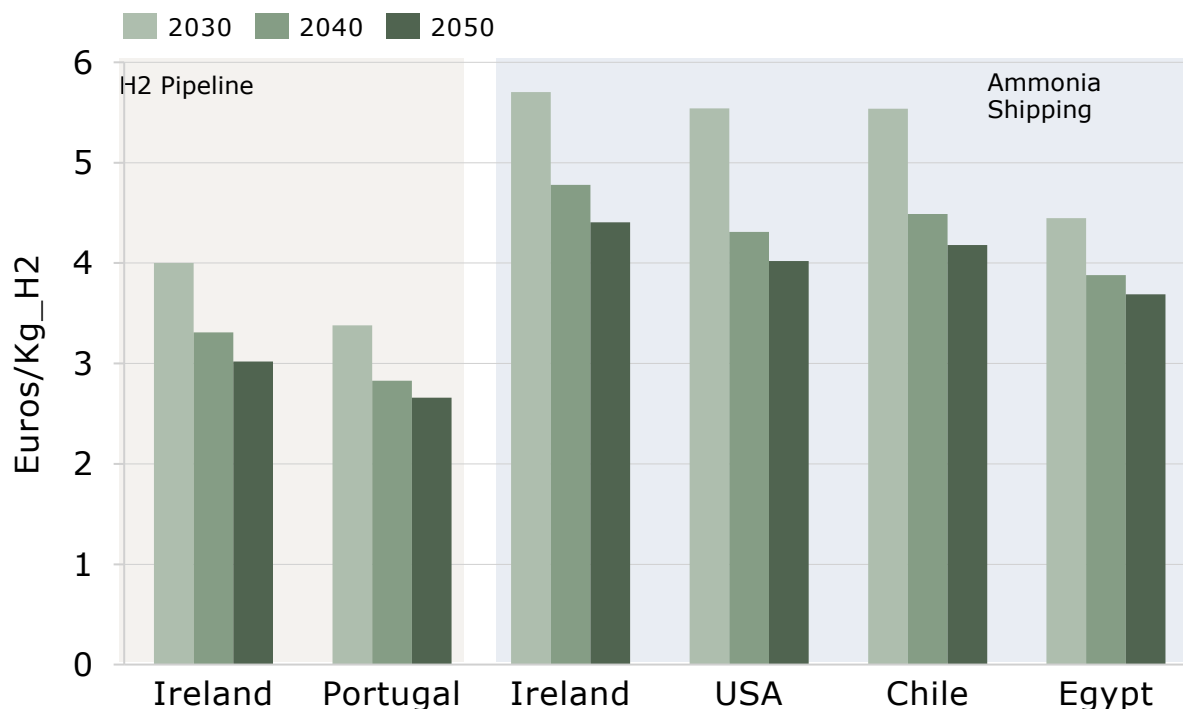


DISCUSSION

- The Economically optimal mode of hydrogen transport can be determined by the delivery distance.
- At distances less than ~6,500 km piped hydrogen is the most economical state to transport but above this ammonia becomes less costly.
 - Ammonia is the most mature option for long distance trade of H₂ - 20 Mt of ammonia are already traded internationally each year with 120 dedicated terminals
 - Standards exist relating to transport of ammonia
- A H2 pipeline to Mainland Europe would be Irelands most economic approach to accessing that market, assuming sufficient export volumes to justify the capital costs

Irish H₂ cost at delivery in DNZ is greater than South European exporters, but has lower costs than non-European exporters using shipped ammonia

LEVELISED COST OF HYDROGEN (AT DELIVERY) TO NWE

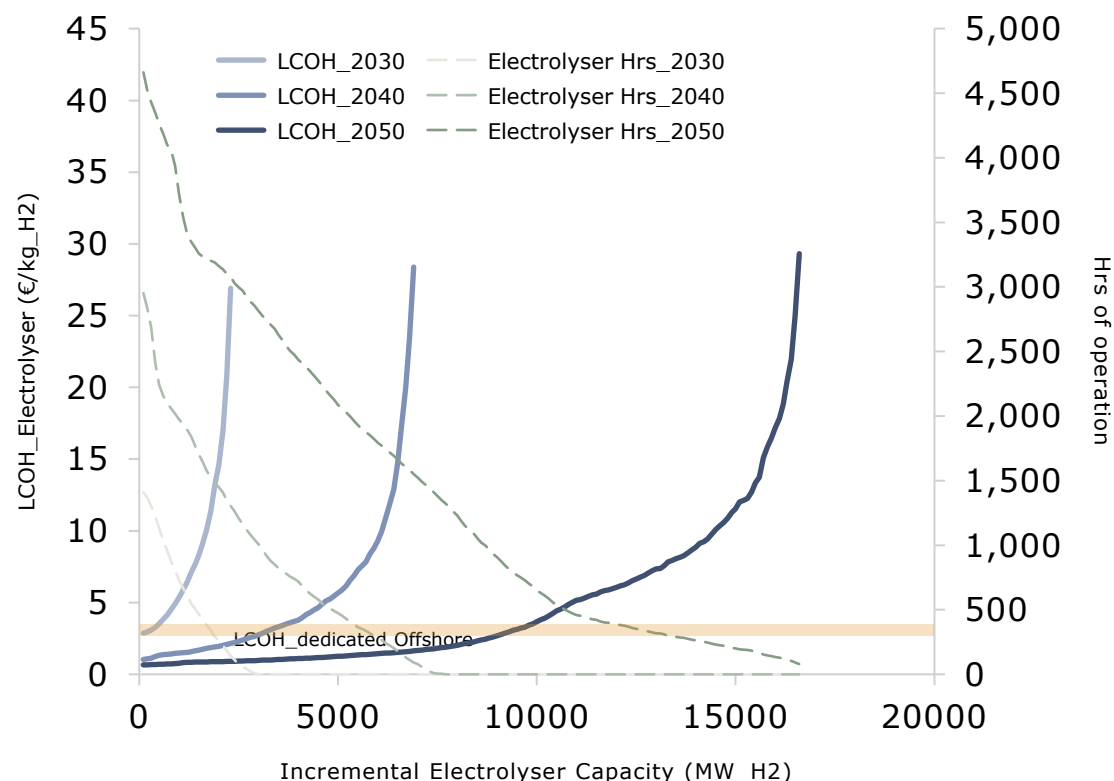


DISCUSSION

- Irish green hydrogen exports face cost competition from south European countries, with cheaper production costs
- The higher production costs of hydrogen from dedicated Offshore in Ireland are offset by lower transportation costs in the total cost at delivery to NWE, when compared to non-European exporters
- Ireland can leverage H2 pipeline mode of delivery to compete in the hydrogen export market, while helping NWE to meet its import targets
- The transportation cost advantage for Ireland comes from:
 - Low cost of delivery with H2 pipeline over shorter distances
 - High conversion and re-conversion costs to Ammonia and back to Hydrogen, adding almost 2€/kg_H2 to the cost at delivery
- The cost advantage for Ireland and other European exporters increase in the long term because of the drop in Capex and Opex for production, while the costs for Ammonia synthesis and cracking remains relatively unchanged.

In the years 2040 and 2050, greater capacity and frequent curtailment lead to higher electrolyser load factors and reduced LCOH

LEVELISED COST OF HYDROGEN AGAINST INCREMENTAL ELECTROLYSER CAPACITY USING SURPLUS ENERGY

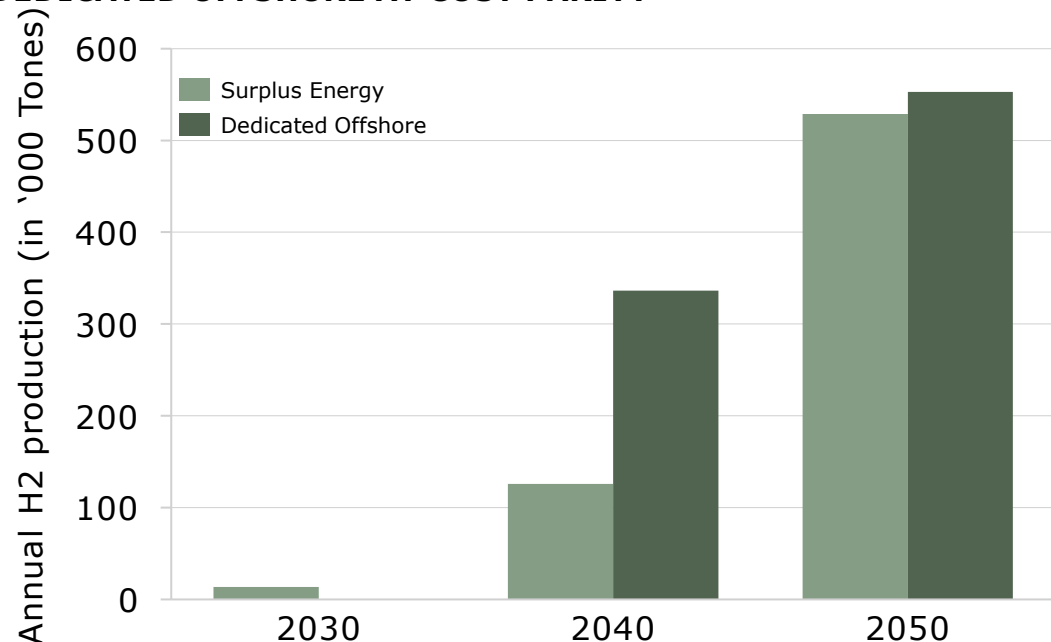


DISCUSSION

- Diverting cheap surplus ORE leads to lower production costs for green hydrogen, in comparison to the ones from dedicated Offshore
- The cost of production increases as the electrolyser capacity is increased, however, in medium to long term there is a significant volume of hydrogen that can be produced at lower/competitive costs compared to dedicated Offshore
- An optimized project configuration can be selected by considering
 - Desired competitive LCOH & production output-volumes
 - Threshold usage of surplus electricity
 - Number of days of SCS storage
 - Cost of surplus energy to produce H₂
- The use of surplus energy could improve Ireland's competitiveness in the long term when compared with other exporters within Europe.

Availability of large amount of cheap energy allows for significant increase in grid connected electrolysers, leading to high green H₂ generation in 2050

ANNUAL H2 PRODUCTION FROM SURPLUS ENERGY AND DEDICATED OFFSHORE AT COST PARITY



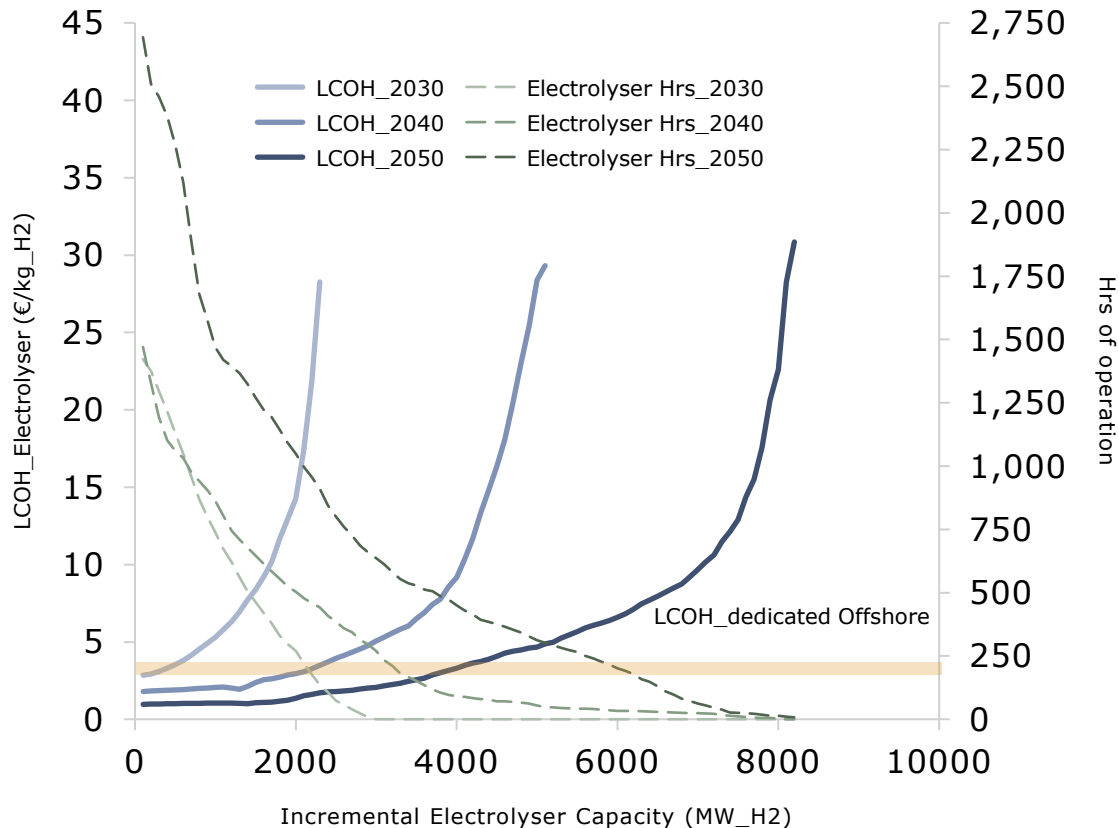
Electrolyser Capacity (MW_H2)			
	2030	2040	2050
Grid Connected (Aggregate capacity)	400	2700	8300
Off Grid	0	2780	4566

DISCUSSION

- These results represent generation levels expected in the 37GW WC IC scenario where an interconnector capacity of 12 GW is assumed
- Greater volumes of H₂ may be achieved in 2040 and 2050 at a lower price than using surplus energy in this scenario. This is not surprising as in this scenario the capacity available far outweighs the domestic power demand, and levels of curtailment are high and result in better load factors for electrolysers
- Achievement of low cost H₂ in this scenario improves Irish export cost competitiveness and could potentially also allow for economic export of derivatives such as ammonia
- Production of H₂ from grid connected offshore wind remains only a fraction of dedicated H₂ production because of decrease in load factors for each incremental increase in electrolyser capacity

Even with low-cost curtailed energy for H₂ production in the DNZ scenario there is a failure to provide a substantial output at a competitive LCOH

LEVELISED COST OF HYDROGEN AGAINST INCREMENTAL ELECTROLYSER CAPACITY USING SURPLUS ENERGY

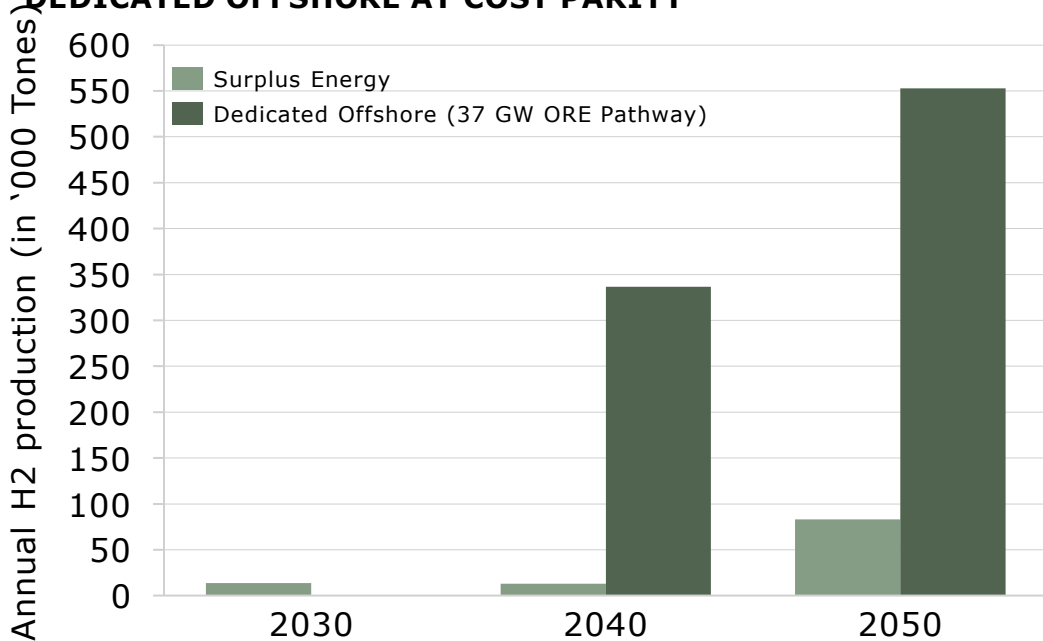


DISCUSSION

- LCOH remains high, even with an assumption of cheap electricity, due to very low load factor of the Electrolyser
- Downsizing the Electrolyser capacity, does drop the LCOH, however the output capacity decreases significantly
- Improvements in cost competitiveness of green hydrogen from surplus electricity in the long term are driven by
 - Increase in the availability of surplus energy
 - Favorable trend in Capex and Opex of electrolyzers
- An optimized project configuration can be selected by considering
 - A competitive LCOH
 - Threshold usage of surplus electricity
 - Number of days of SCS storage (if within the scope)

Most production under the DNZ scenario comes from dedicated capacity rather than generation from curtailed volumes

ANNUAL H2 PRODUCTION FROM SURPLUS ENERGY AND DEDICATED OFFSHORE AT COST PARITY



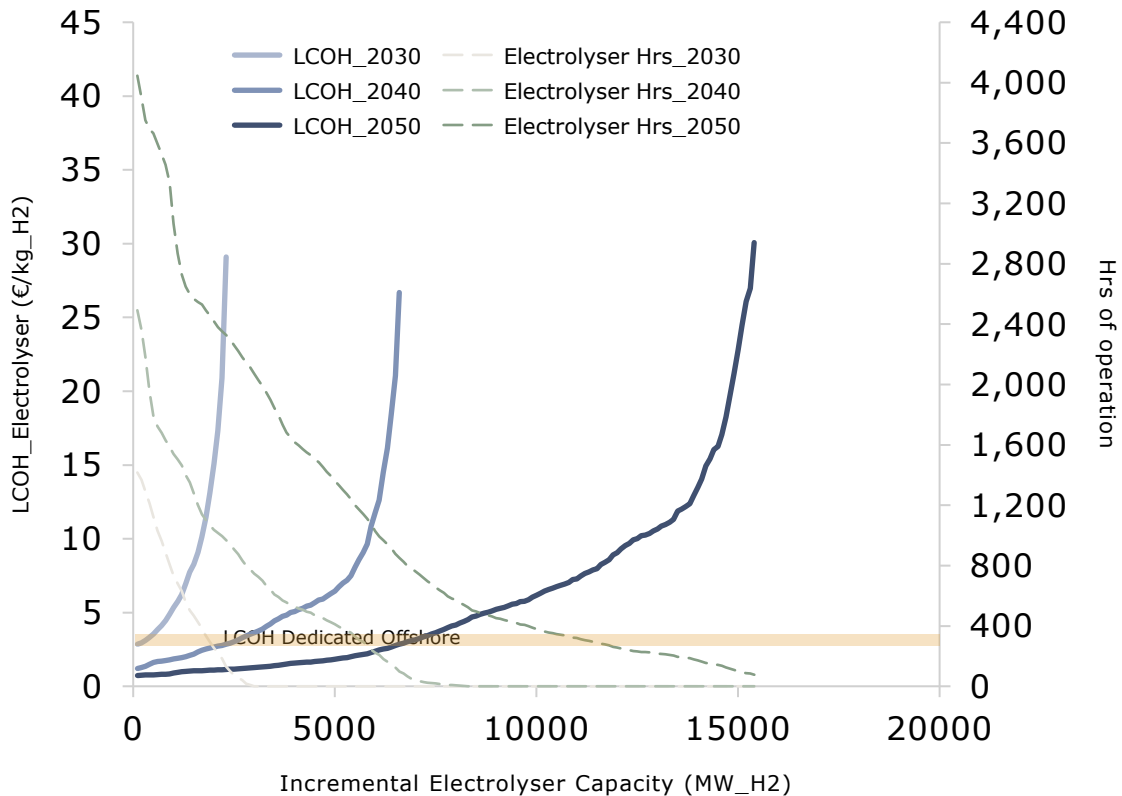
Electrolyser Capacity (MW_H2)			
	2030	2040	2050
Grid Connected (Aggregate capacity)	400	400	1900
Off Grid (37GW ORE Pathway)	0	2780	4566

DISCUSSION

- These results represent generation levels expected in the DNZ scenario.
- High intermittency of surplus energy supply results in low electrolyser load factor, thereby producing low overall H2 volumes
- Hydrogen production from surplus energy will remain a fraction of the annual production that could be achieved from a dedicated Offshore

Increasing the level of interconnection reduces the level of available surplus power in 37GW Stretch IC Scenario when compared to 37GW WC IC

LEVELISED COST OF HYDROGEN AGAINST INCREMENTAL ELECTROLYSER CAPACITY USING SURPLUS ENERGY

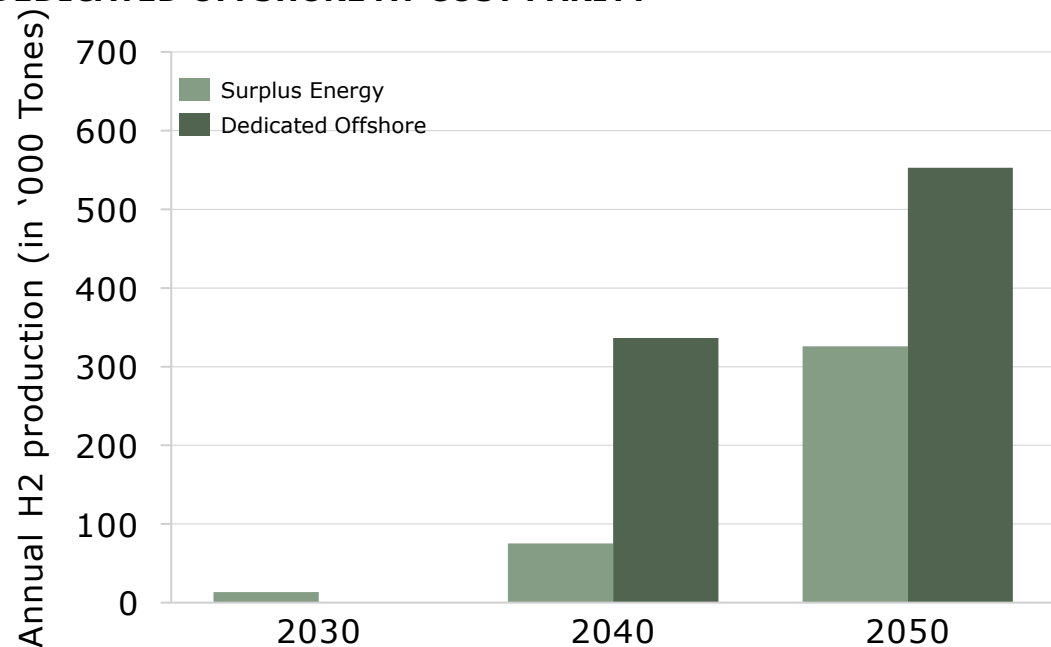


DISCUSSION

- With a high renewable generation capacity in 2050 there will likely be more hours where SEM prices will be low and there will be greater opportunities for export
- Greater interconnection in this scenario, 17 GW, facilitates this and provides a market for curtailed energy that will reduce the level of surplus available for H₂ production

H2 production is reduced in comparison to 37GW WC_IC case, because of greater interconnection and reduced surplus energy

ANNUAL H2 PRODUCTION FROM SURPLUS ENERGY AND DEDICATED OFFSHORE AT COST PARITY



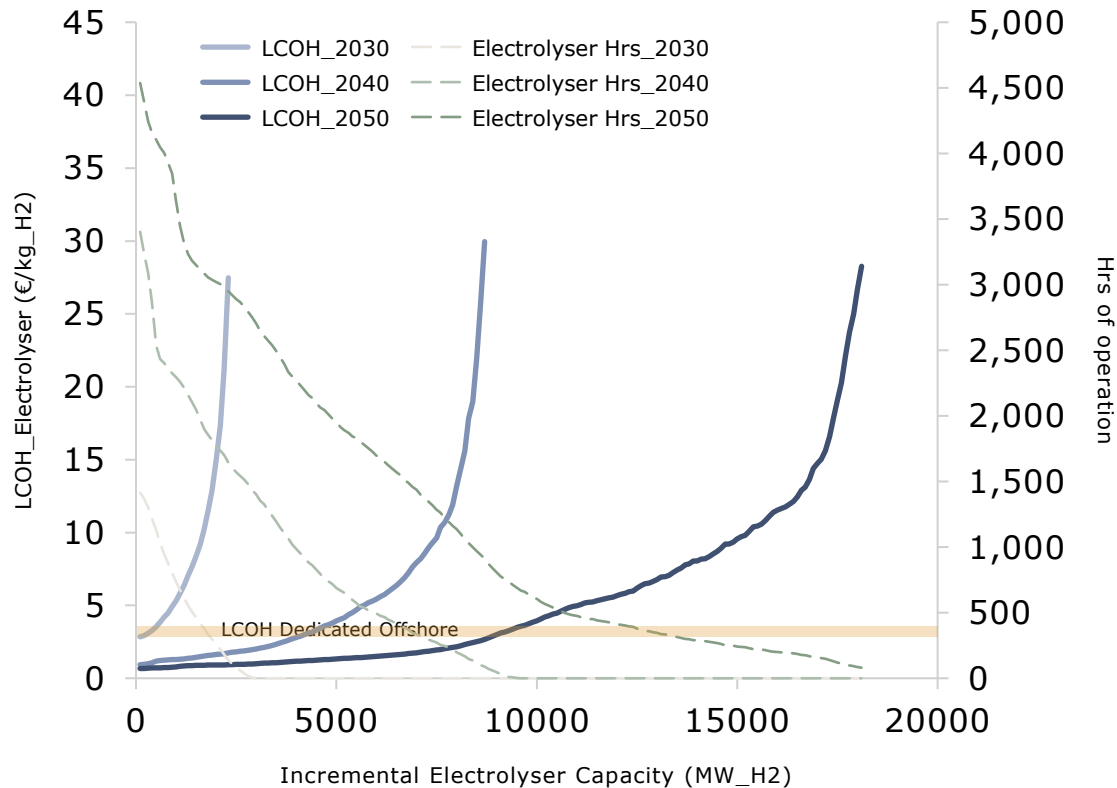
Electrolyser Capacity (MW_H2)			
	2030	2040	2050
Grid Connected (Aggregate capacity)	400	1800	5800
Off Grid	0	2780	4566

DISCUSSION

- These results represent generation levels expected in the 37GW Stretch IC scenario with an interconnector capacity of 17 GW
- Generation of H2 from surplus offshore wind remains higher in this scenario for 2050 but is lower than the 37GW WC IC scenario as there is greater export of wind via interconnectors reducing the level of curtailment
- Production of H2 from dedicated offshore wind remains the dominant source of green hydrogen

Greater ORE capacity increases curtailment but this is balanced by increased interconnector capacity in the 50 GW Stretch IC Scenario

LEVELISED COST OF HYDROGEN AGAINST INCREMENTAL ELECTROLYSER CAPACITY USING SURPLUS ENERGY

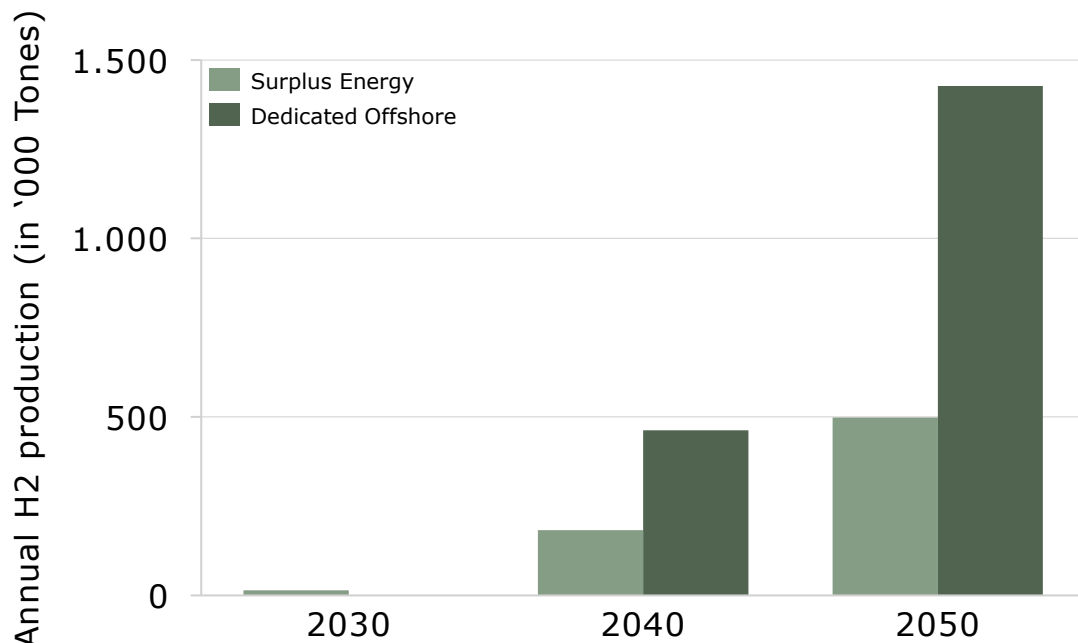


DISCUSSION

- Similar to the 37 GW Stretch IC scenario, levels of interconnection here (17 GW) result in reduced curtailment and consequently reduced available surplus for H₂ production compared to the well-connected scenarios
- The potential levels of curtailed wind still remain high enough to bring down costs of H₂ in the long term and may result in increased cost competitiveness of Irish exports, both H₂ and derivatives

In spite of the greater level of dedicated capacity in the 50 GW Stretch IC scenario, greater volumes of low-cost H₂ are possible from surplus energy

ANNUAL H2 PRODUCTION FROM SURPLUS ENERGY AND DEDICATED OFFSHORE AT COST PARITY



Electrolyser Capacity (MW_H2)			
	2030	2040	2050
Grid Connected (Aggregate capacity)	400	3700	8100
Off Grid	0	3818	11789

DISCUSSION

- These results represent generation levels expected in the 50GW Stretch IC scenario in which interconnector capacity is 17 GW and dedicated capacity also increases to 15 GW
- Potential levels of H2 generation at the same cost favour the use of dedicated power in this scenario in 2040 and 2050.

The competitive price of hydrogen is a function of pipeline transport and economic volumes of curtailed electricity

- Using dedicated offshore wind for hydrogen in Ireland would generate an LCOH of €3.71/kg in 2030, falling to €3.02/kg in 2040 and €2.73/kg in 2050
- This price of hydrogen is competitive with domestic production in other European countries but would have additional costs associated with transport that would make it less competitive with that same domestic production
- Adding these costs for pipeline transport would give delivered cost of hydrogen of €4.00/kg in 2030, falling to €3.31/kg in 2040 and €3.02/kg in 2050
- These results suggest that Ireland would have a c. €0.40/kg advantage over international delivered costs of hydrogen (although this gap narrows as time goes on)
- Using this same approach for delivered costs via ship (which would mean conversion into ammonia) would amount to higher costs of €5.70 in 2030, falling to €4.78/kg in 2040 and €4.41/kg in 2050
- The consequence of building additional ORE means that there will be higher curtailed amounts of electricity which if diverted to hydrogen production would give a lower LCOH and delivered cost
- This study suggests that under the DNZ scenario none of this curtailed electricity would be economic
- Under the higher build out rates this study suggests that there could be as much as 13-22TWh of electricity that would be economic to utilise in hydrogen production, rising up to 55TWh in the high case



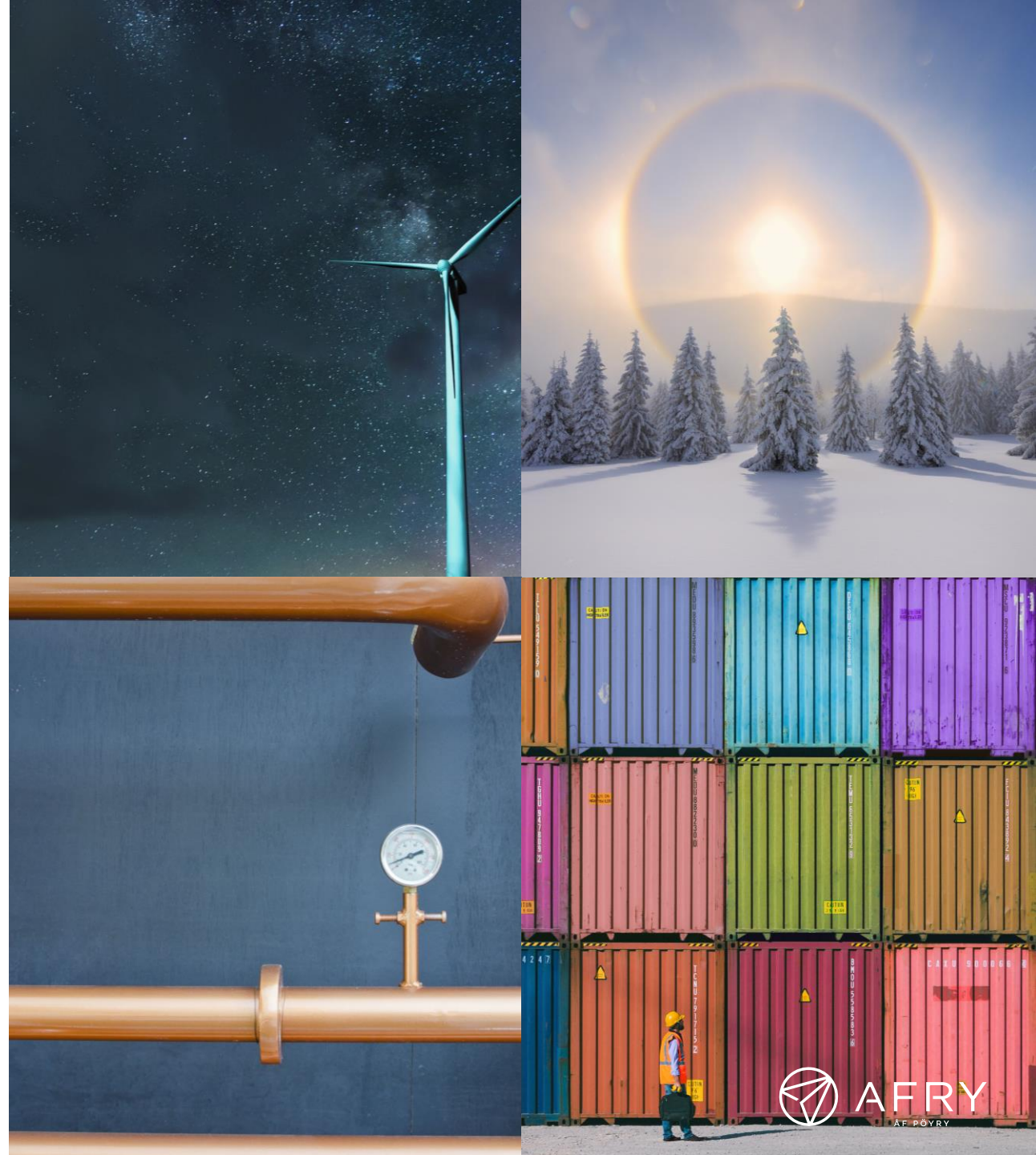
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7. Hydrogen Exports

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7.1 Hydrogen for Export

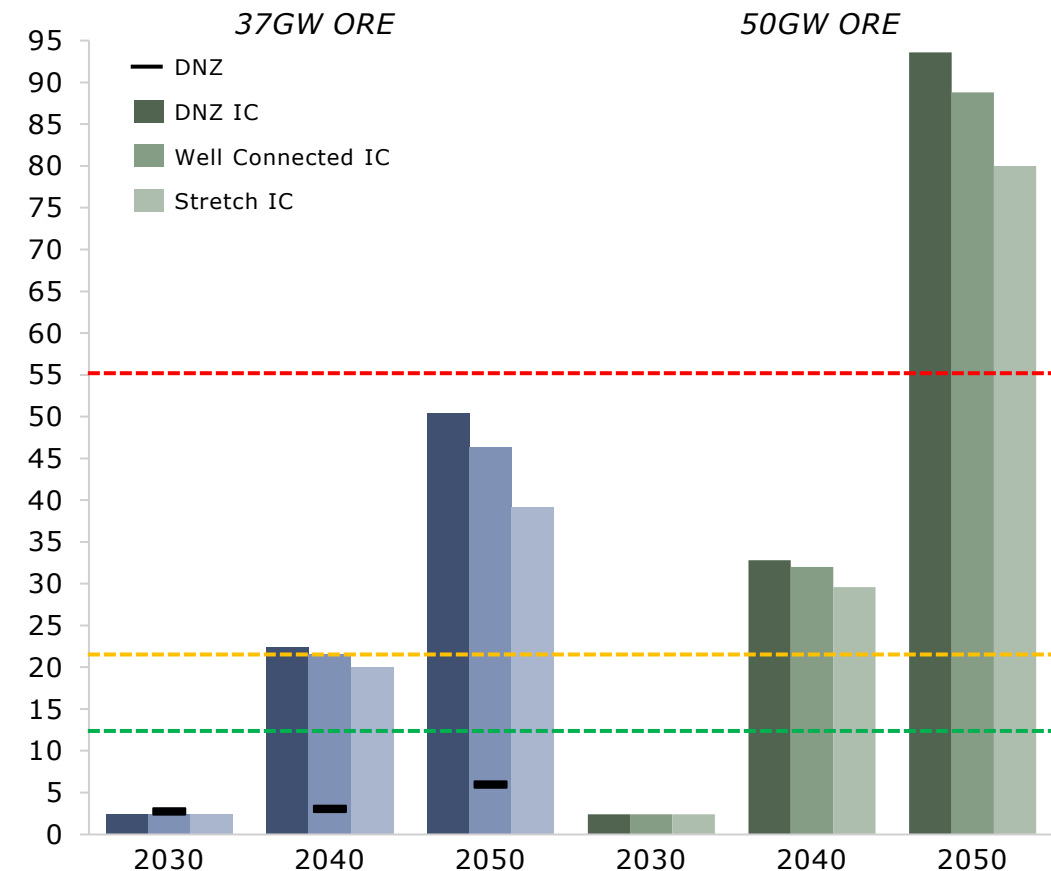
7.2 Hydrogen derivatives for Export



HYDROGEN EXPORTS

There is potential to produce considerable volumes of green hydrogen from surplus power in Ireland, against a backdrop of growing demand in Europe

HYDROGEN (TWH_{H2}) PRODUCTION FROM SURPLUS



80% conversion factor assumed for conversion of power to hydrogen

OVERVIEW

- Whilst the theoretical maximums for hydrogen production are quite high, those which make economic sense are considerably lower
- The results suggest that not all electricity would be utilised for hydrogen under the scenarios and some additional demand for electricity or sufficient storage would be required to ensure minimum waste
- It is also important to note that since curtailed wind is intermittent and unpredictable, the load factors for electrolysers could be lower and the subsequent economics somewhat fluid
- Nevertheless, this study suggests that there would be sizeable economic hydrogen available after all domestic demand is met and so exports will be an important part of an all Ireland hydrogen system
- Whether this is as hydrogen through pipelines, ammonia through shipping or some other derivative products or good will be a matter of economics and policy beyond this study

HYDROGEN EXPORTS

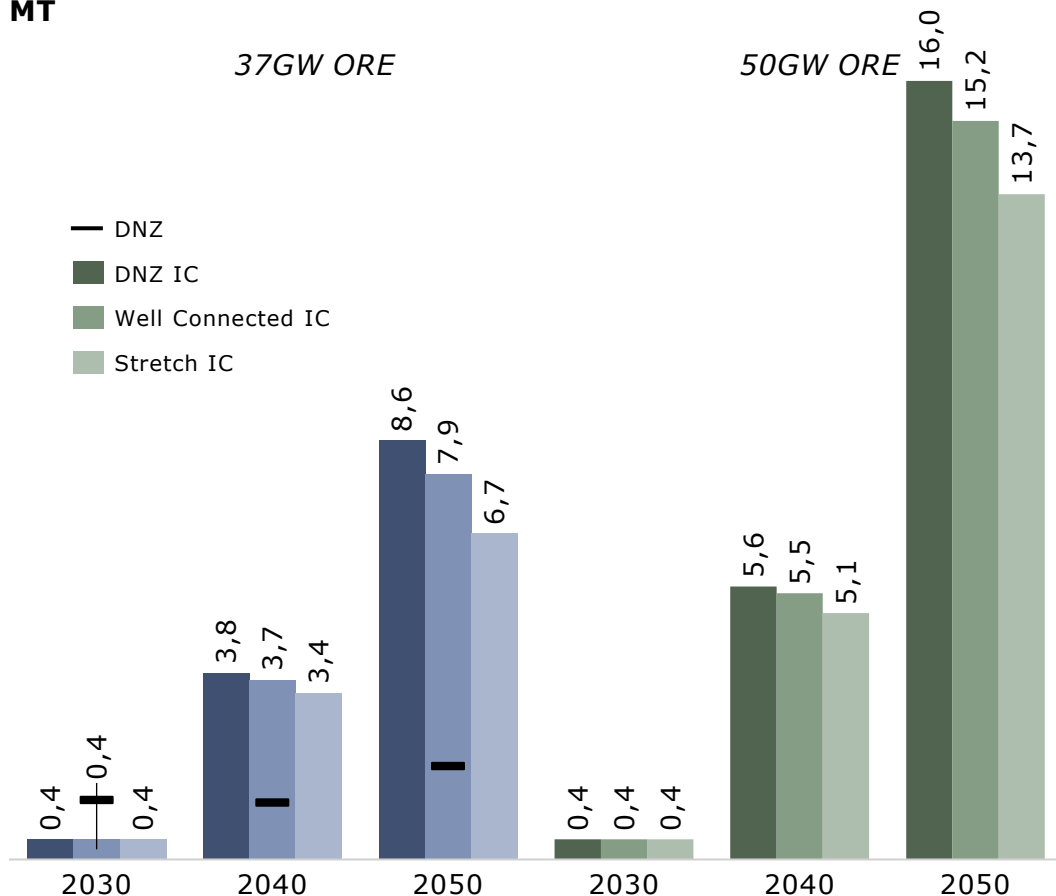
Potential to meet domestic demand exists across all scenarios with excess H₂ available for other uses including meeting EU targets for Jet and Ship fuels

Scenario			Supply			Demand	Remainder	Other demand potential			Export
			Off Grid (TWh_H2)	On Grid (TWh_H2)	Total			Domestic Demand (TWh_H2)	Ammonia	eSAF	
16 GW	DNZ	2030	0.00	2.76	2.76	0.50	2.26	2.45	0.065	0.55	-0.80
		2040	0.00	9.50	9.50	6.93	2.58	2.98	0.55	6	-6.95
		2050	0.00	18.46	18.46	13.71	4.75	3.5	1.3	13.5	-13.55
37 GW	Well Connected IC	2030	0.00	3.33	3.33	0.50	2.83	2.45	0.065	0.55	-0.24
		2040	13.31	15.21	28.52	6.93	21.60	2.98	0.55	6	12.07
		2050	21.25	38.88	60.13	13.60	46.53	3.5	1.3	13.5	28.23
	Stretch IC	2030	0.00	2.76	2.76	0.50	2.26	2.45	0.065	0.55	-0.80
		2040	13.31	13.48	26.79	6.93	19.87	2.98	0.55	6	10.34
		2050	21.25	31.68	52.93	13.63	39.30	3.5	1.3	13.5	21.00
50 GW	Stretch IC	2030	0.00	2.76	2.76	0.50	2.26	2.45	0.065	0.55	-0.80
		2040	18.29	18.03	36.32	6.93	29.39	2.98	0.55	6	19.86
		2050	54.86	38.57	93.43	13.60	79.83	3.5	1.3	13.5	61.53

HYDROGEN EXPORTS

Ammonia is imported into Ireland to produce fertilisers, this demand could be met by converting hydrogen to this derivative and supply global demand

AMMONIA PRODUCTION FROM EXCESS RES MT



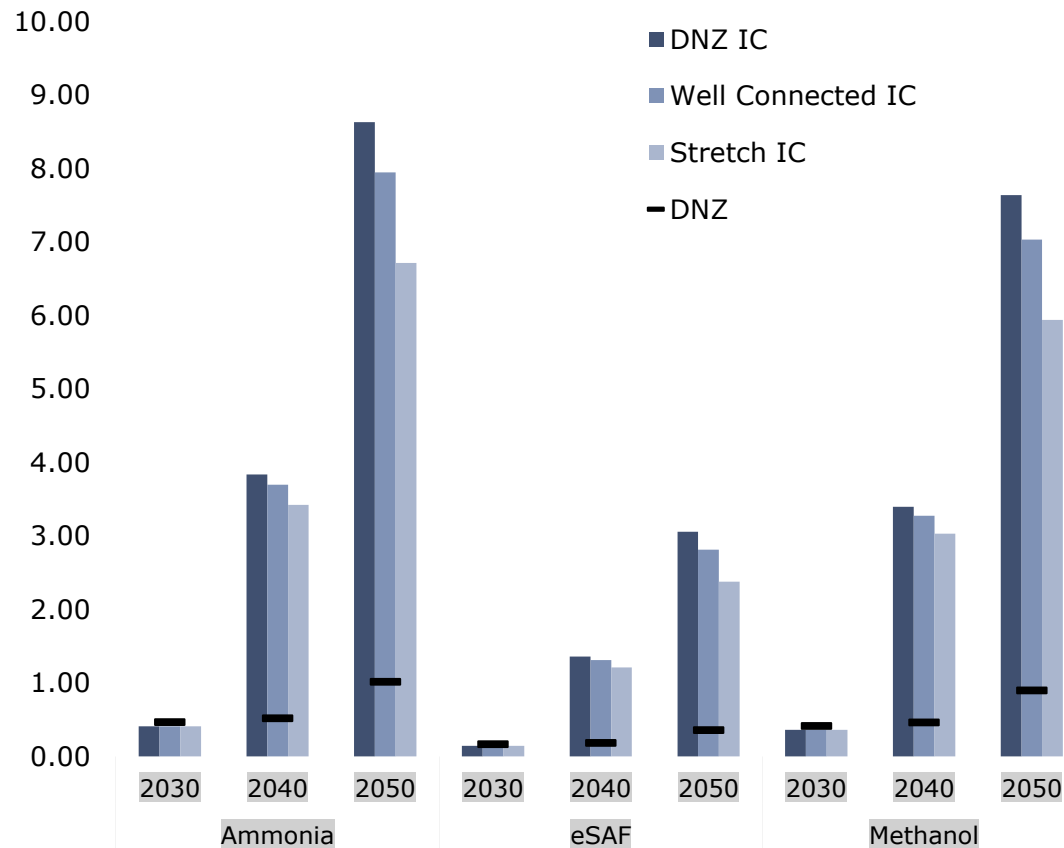
DISCUSSION

- Irish consumption of fertiliser is the equivalent of 2.45 TWh of Hydrogen (0.42 Mt NH₃) and not expected to grow significantly.
- All nitrogen-containing fertiliser produced in Ireland relies on imported ammonia
- Ammonia plant in Europe are ~40 years old in an expected lifetime of 50 years, there is scope for replacement with green ammonia plant in the next decade.
- All modelled surplus energy scenarios meet 98-100% of domestic fertiliser needs for H₂ in Ireland by 2030.
- Global Market
 - 60% of Hydrogen used in industry in 2022 was used for ammonia (NH₃) production.
 - 80% of global ammonia production is used in fertilisers. Produced predominantly using natural gas. Ammonia prices have displayed volatility as a result.
 - Global production is expected to grow by 40% by 2050 in response to demand increases stemming from economic and population growth

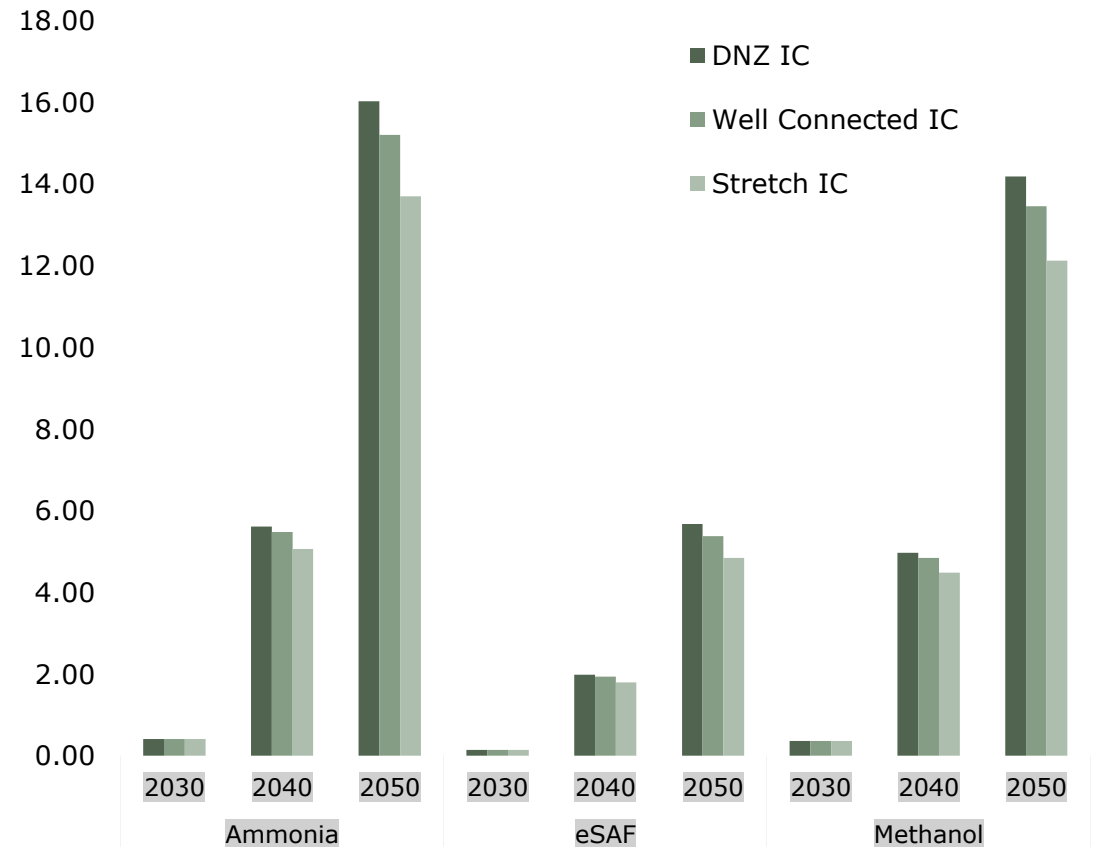
HYDROGEN EXPORTS

In addition to ammonia there are other green hydrogen derivatives that could be exported or used domestically in new industry or transport

HYDROGEN DERIVATIVE PRODUCTION DNZ & 37 GW (MILLION TONS)



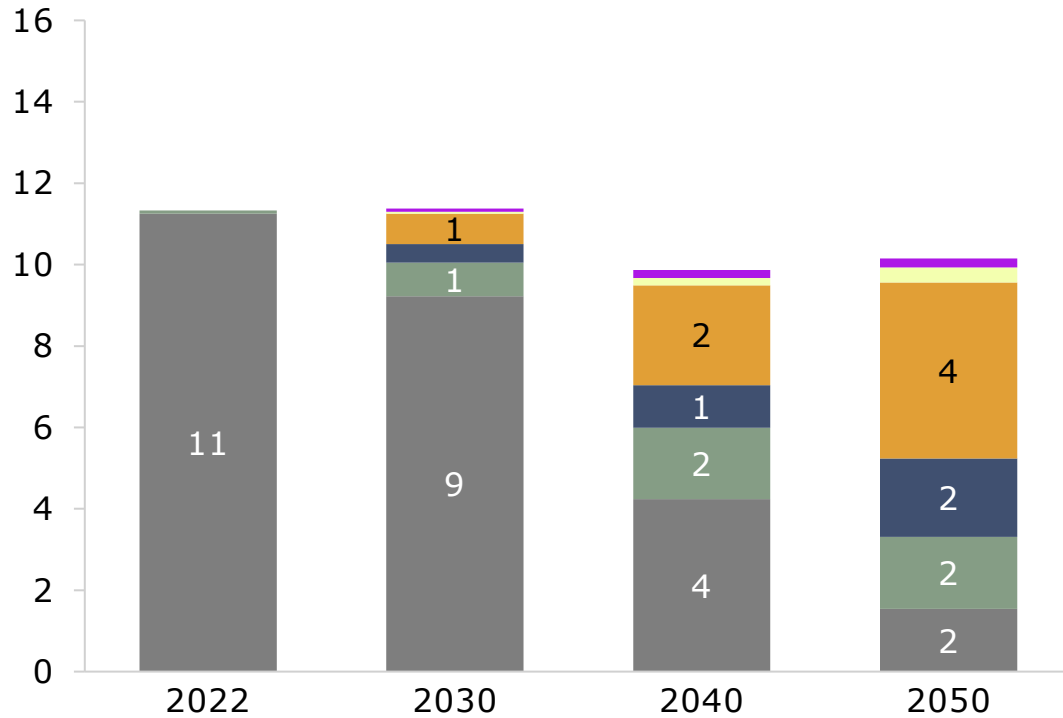
HYDROGEN DERIVATIVE PRODUCTION 50 GW (MILLION TONS)



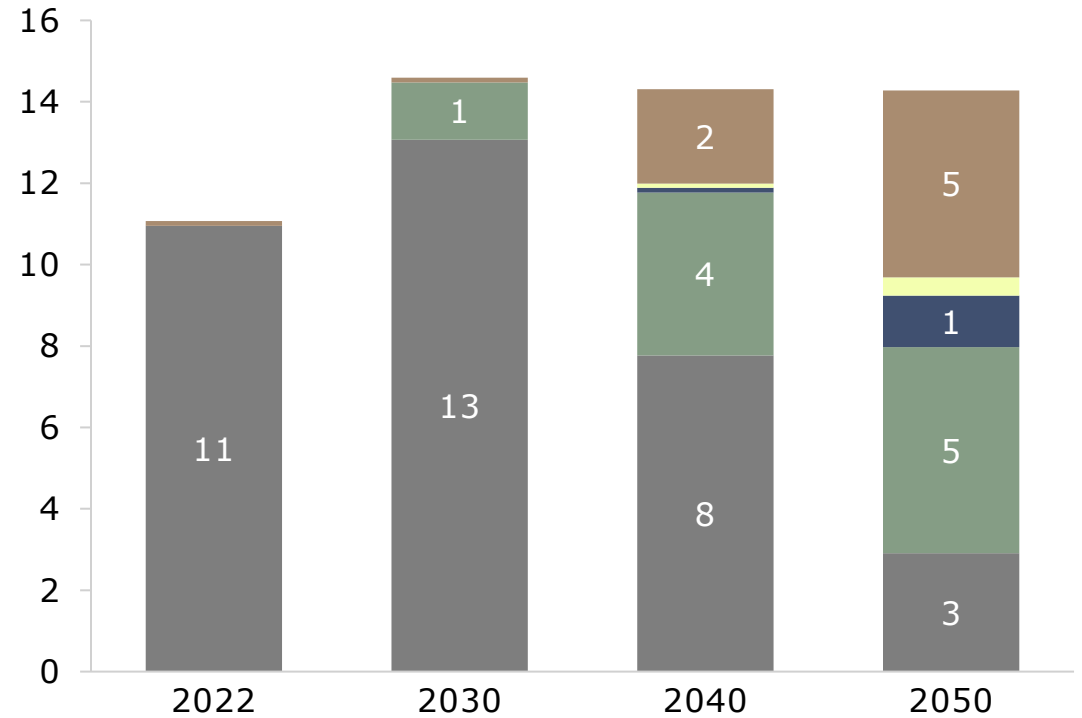
HYDROGEN EXPORTS

By 2050 ammonia and synthetic kerosene hold a significant share in maritime and aviation energy consumption respectively, with hydrogen showing notable growth

GLOBAL MARITIME ENERGY CONSUMPTION (EJ)



GLOBAL AVIATION ENERGY CONSUMPTION (EJ)



■ Methanol
 ■ Synthetic kerosene
 ■ Electricity
 ■ Ammonia
 ■ Hydrogen
 ■ Biofuels
 ■ Fossil fuels

HYDROGEN EXPORTS

Combining domestic dedicated and surplus hydrogen production suggests exports of 15-20TWh in 2040 rising to over 30TWh in 2050*

Scenario			Electrolyser Capacity (MW_H2)			H2 Production (GWh_H2)				Pipeline H2 from Surplus + Dedicated (GWh_H2) NB: Different from WS1 modelled export H2			Storage capacity needed (GWh_H2)		
			Off Grid	On Grid_ ORE Surplus	Total	Off Grid	On Grid Domestic	On Grid_ ORE Surplus	Total	Off Grid	On Grid ORE Surplus	Total	Off Grid (optimised at capacity turnover of 9.14)	On Grid_ ORE Surplus (assumed a capacity turnover of 7)	Total
16 GW	DNZ	2030	0	400	400	0	500	453	953	0	453	453	0	65	65
		2040	0	400	400	0	6930	435	7365	0	435	435	0	62	62
		2050	0	1900	1900	0	13710	2773	16483	0	2773	2773	0	396	396
37 GW	Well Connected IC	2030	0	400	400	0	500	453	953	0	453	453	0	65	65
		2040	2780	2700	5480	11206	6930	4190	22326	11206	4190	15396	1225	600	1825
		2050	4566	8300	12866	18410	13600	17615	49625	18410	17615	36025	2011	2516	4527
	Stretch IC	2030	0	400	400	0	500	452	952	0	452	452	0	65	65
		2040	2780	1800	4580	11206	6930	2510	20646	11206	2510	13716	1225	360	1585
		2050	4566	5800	10366	18410	13630	10850	42890	18410	10850	29260	2011	1550	3561
50 GW	Stretch IC	2030	0	400	400	0	500	453	953	0	453	453	0	65	65
		2040	3818	3700	7518	15393	6930	6090	28413	15393	6090	21483	1682	870	2552
		2050	11789	8100	19889	47525	13600	16581	77706	47525	16581	64106	5193	2370	7563

* Assuming no additional domestic hydrogen demand

HYDROGEN EXPORTS

Ireland has the opportunity to export green hydrogen profitably

- Ireland has good wind resources and so can produce hydrogen from dedicated ORE reasonably competitively
 - This report has shown that Ireland is broadly competitive against green hydrogen produced around NW Europe
 - Although regions such as North Africa and Chile can produce green hydrogen at a lower cost (due to optimised hybrid RES) the delivered cost is expected to be higher than Ireland
- Ireland can comfortably produce hydrogen to supply its domestic needs completely and competitively
 - This means that Ireland may be able to competitively supply hydrogen to mainland NW Europe assuming that a pipeline connection is constructed
 - The volume of hydrogen that is likely to be exported is not expected to become significant until 2040 based on the scenarios investigated in this report
 - This volume in 2040 would likely amount up to 20TWh (0.6Mt) rising to 30TWh in 2050 (1Mt) but could be as high as 64TWh (2Mt)
- Derivative products such as ammonia and methanol could also be competitive for exports

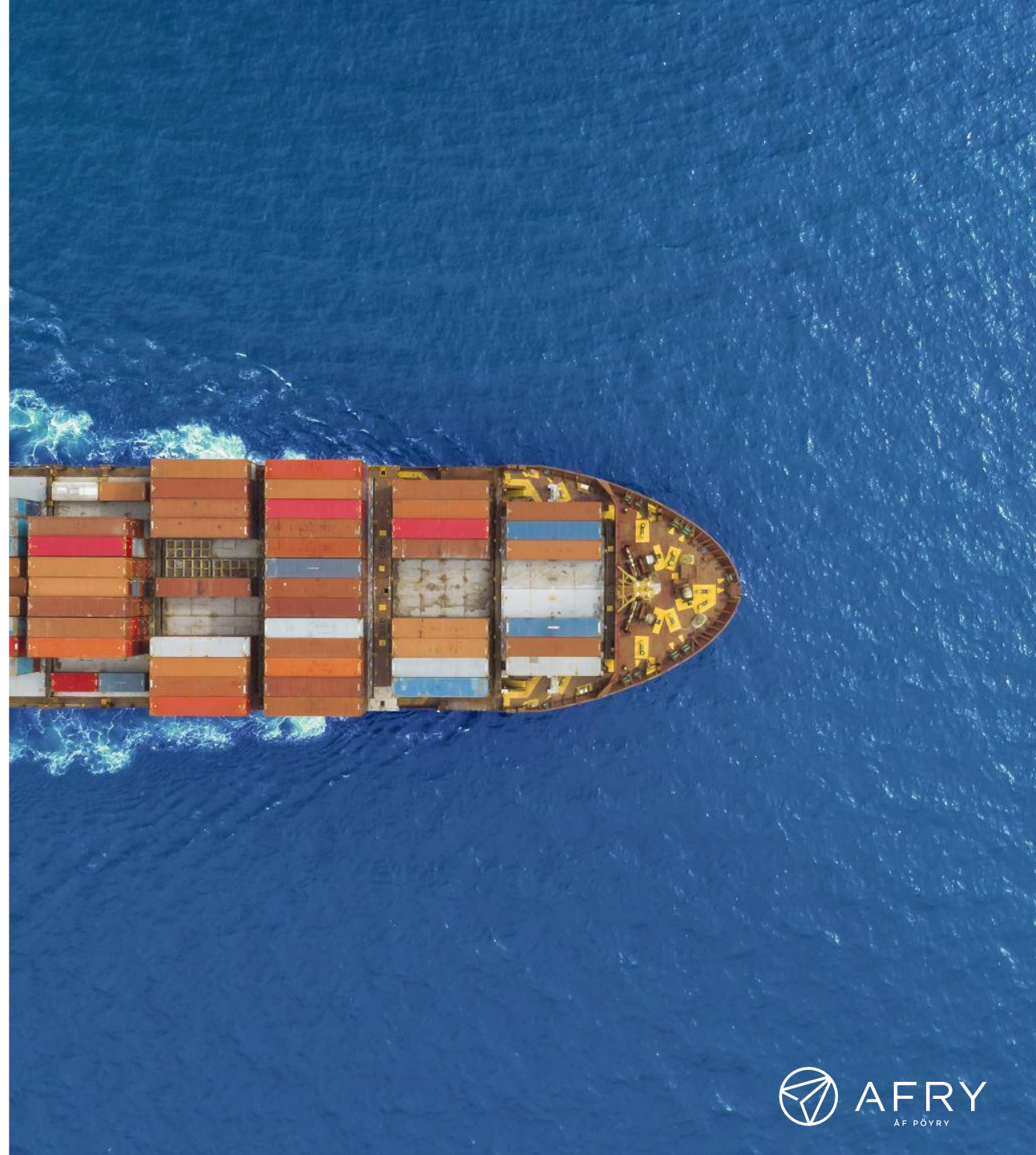
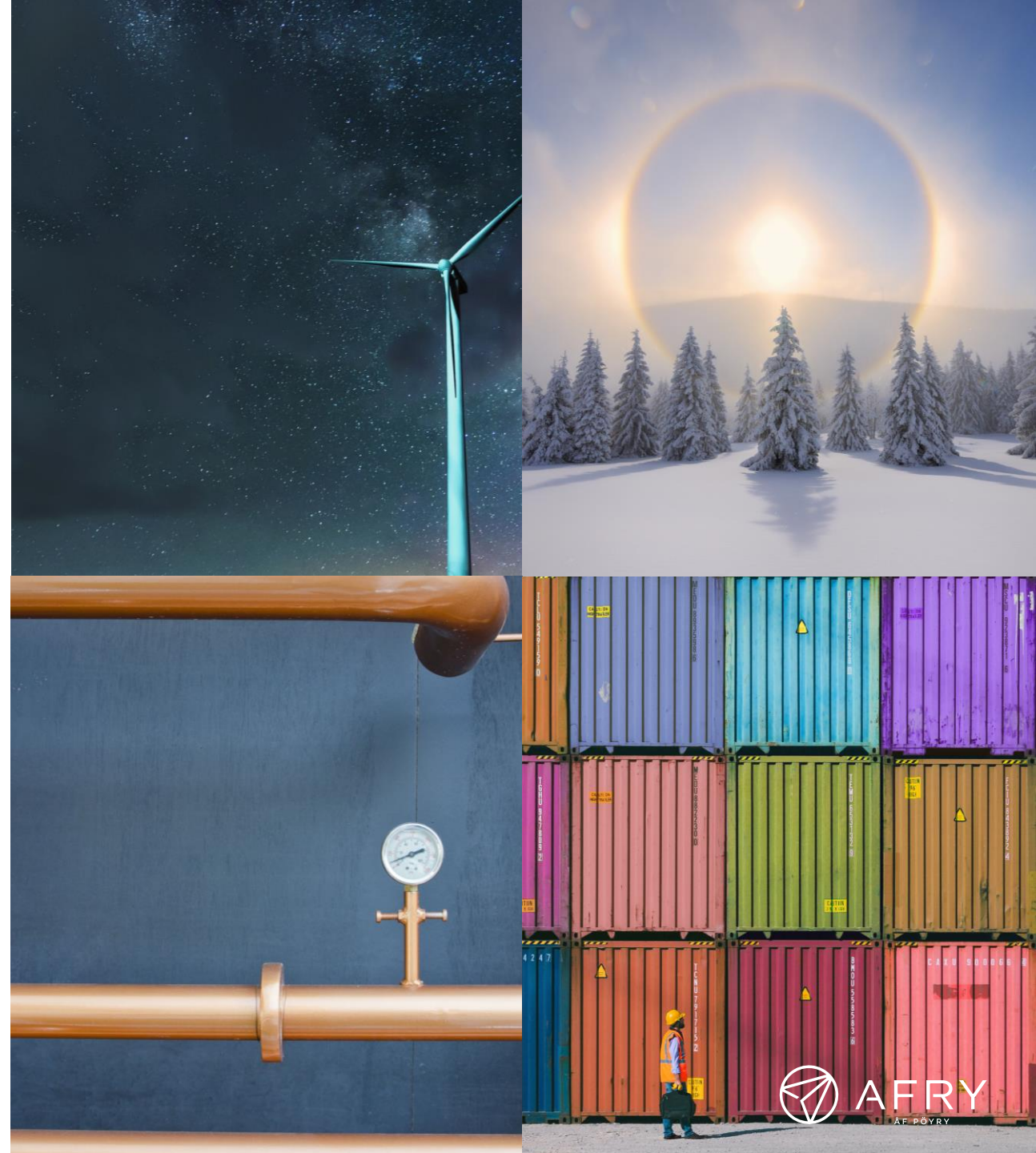


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8.1 Global Competitors	
8.2 Stability of Supply	
8.3 Practical Considerations	
8.4 Opportunities and Risk	



A credible route to market will need to connect production to demand in the most cost-effective way

- This report outlines the likely hybrid nature of any electricity and hydrogen system using ORE in Ireland
- Certainly, Ireland can competitively produce hydrogen the key question is the balance between encouraging domestic demand and uses or to export
- Currently, Ireland is investigating how much of its offshore wind resource to develop and this decision will be a major influence on the relative ratio between domestic use and exports
- Despite this the high-level analysis suggests that 20TWh is not an unreasonable base case of exports to assume after domestic demand is fully met
- Any route to market will therefore require sufficient storage and infrastructure to link demand centres in Ireland and provide a credible export route to a major offtaker
- Connecting Ireland with the mainland EU market would seem to be the best means to accomplish this as Germany has emerged as a major near term offtaker from imports
- Since Ireland will have to compete globally for market share it is important to understand if those low cost regions can compete practically as well as on price

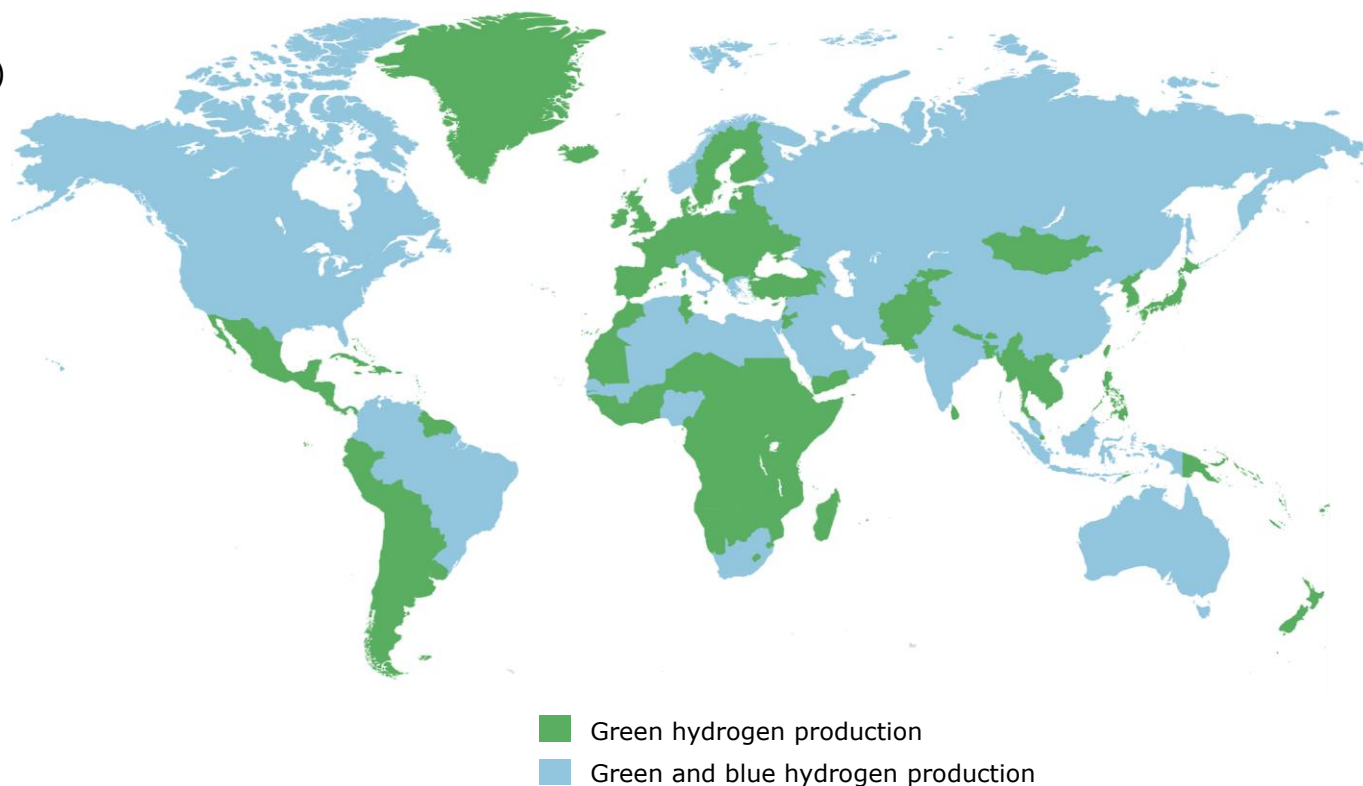


Irish hydrogen will be competing globally for market share against other production technologies as well as transport options

PROJECTIONS FOR HYDROGEN SUPPLY

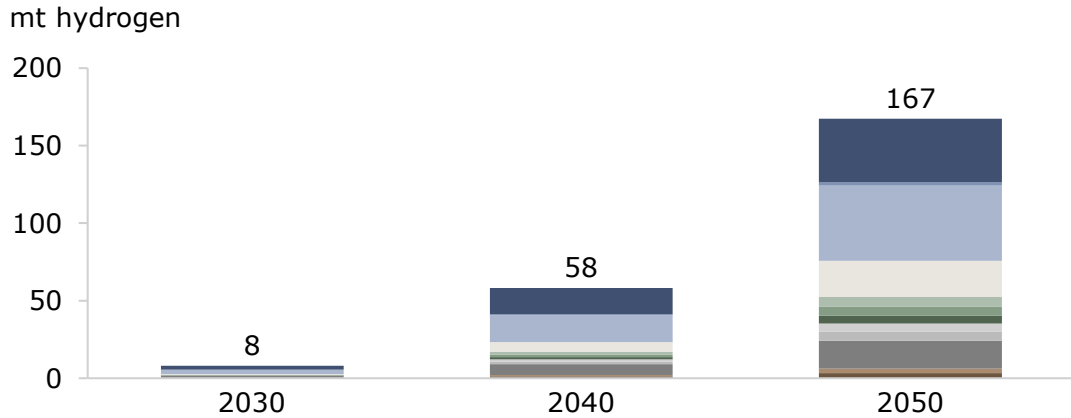
- In its simplest form the production of hydrogen can be achieved through electricity (green) or gas (blue)
- Green hydrogen will dominate where RES is cheapest and price of production will vary according to natural RES endowment before other factors
- The top producers of green hydrogen will therefore be the Middle East, North Africa, Australia and Chile
- Blue hydrogen production is assumed to happen only in gas producing regions as CO₂ storage sites are likely to be better in producing markets and will initially be cheaper than green
- The top producers of blue hydrogen are Norway, Russia, China, USA and Middle East
- China and Russia are expected to be domestically self-sufficient with little to no exports
- This means Ireland will be competing for European market share with Chile, Australia, Middle East and North Africa

HYDROGEN PRODUCTION POTENTIAL AND TECHNOLOGY



Global hydrogen demand is forecast to be between 5k-18kTWh by 2050 meaning there will be ample market opportunity to compete globally

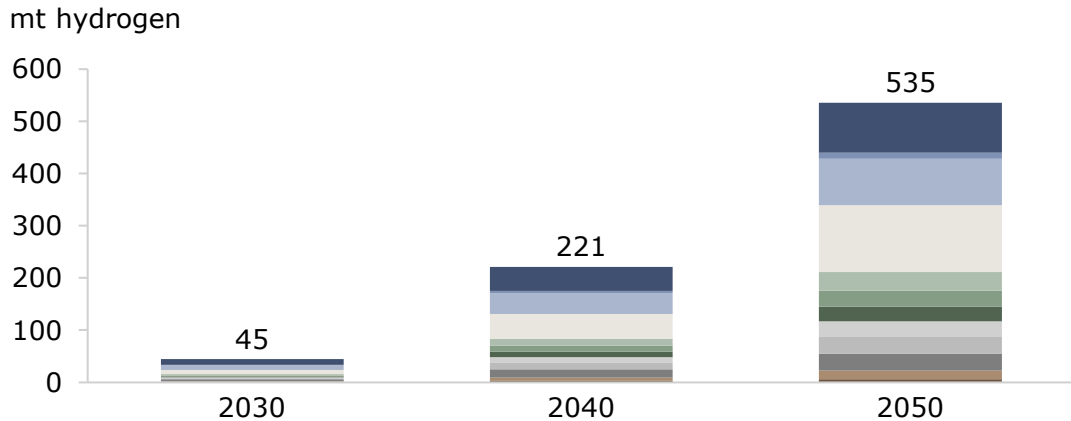
LOW CARBON HYDROGEN DEMAND - GRADUAL DECARBONISATION



COMMENTARY

- Under the gradual decarbonisation scenario, low carbon hydrogen demand will be heavily concentrated in Europe, Japan and South Korea, with minor contribution to global demand from other markets
- Under the rapid decarbonisation scenario, China overtakes Europe as the biggest demand hub for low carbon hydrogen and hydrogen demand in North America is at the European level by 2050

LOW CARBON HYDROGEN DEMAND - RAPID DECARBONISATION

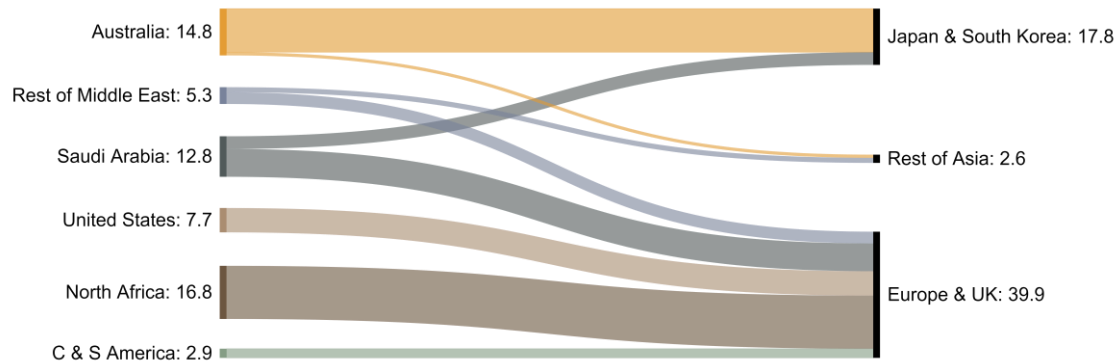


Under modelled global trade flows, Ireland would likely compete with hydrogen from Saudi Arabia, USA and North Africa in Europe

2030 TRADE FLOWS: GRADUAL DECARBONISATION (MT)



2050 TRADE FLOWS: GRADUAL DECARBONISATION (MT)



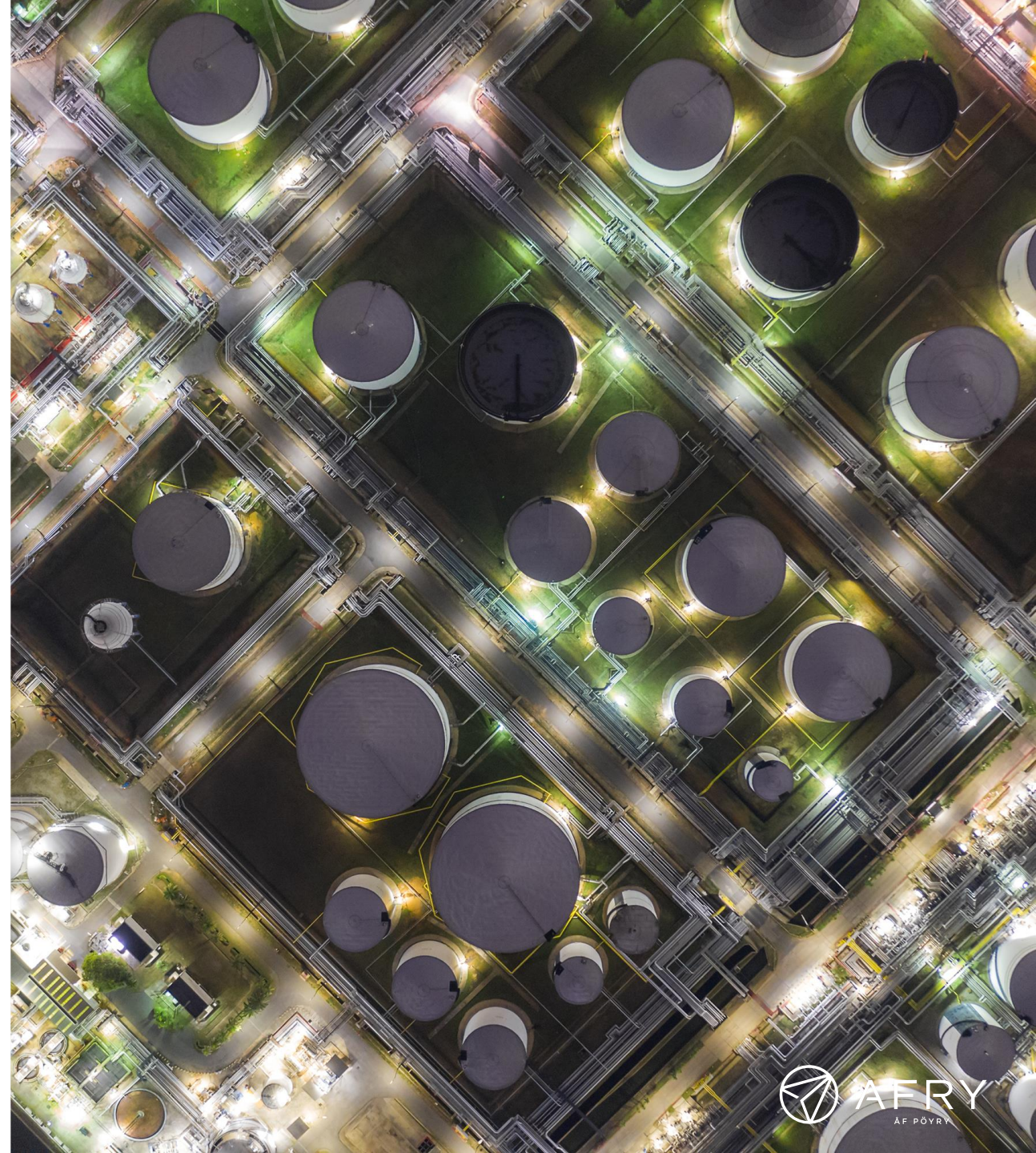
Source: AFRY Global hydrogen trade model

COMMENTARY

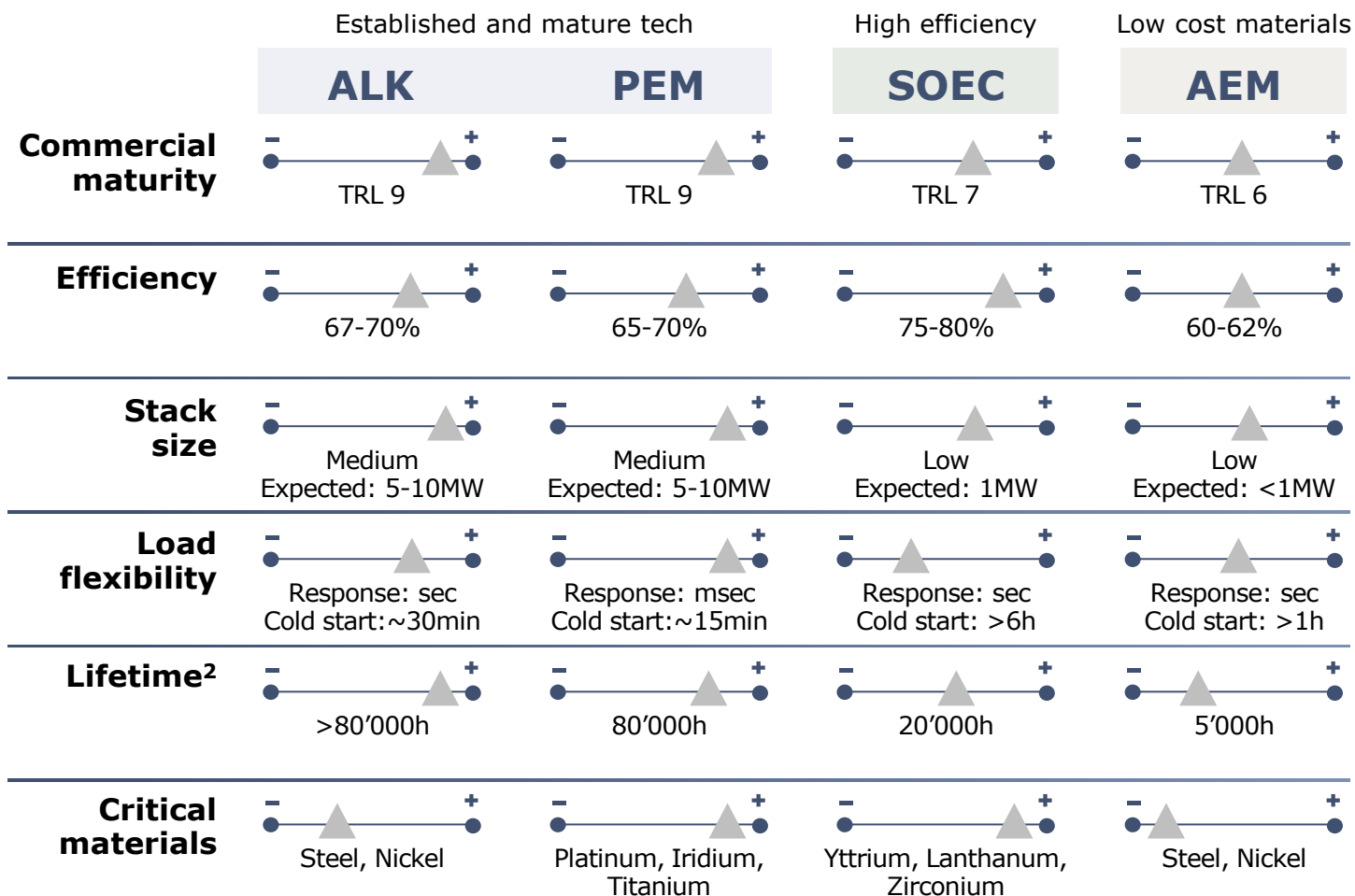
- The trade flows in 2030 are dominated by exports from the US to Europe, supported by the subsidy for green hydrogen available under the Inflation Reduction Act (IRA)
- Saudi Arabia exports will likely be Ammonia although there have been recent feasibility studies for a pipeline via Egypt into Southern Europe that would be a gamechanger
- Pacific rim countries are unlikely to export to Europe given the large potential demand from Japan and South Korea
- It would therefore be expected that the main competition risk would come from a North African pipeline or USA exports supported by subsidy (after 2032 this subsidy would expire)
- North Africa becomes a major exporter by 2050 which is a mix of green hydrogen from Morocco and blue hydrogen in particular from Algeria

A key consideration of route to market is stability of supply

- Depending on the type of electrolyser used coupled with the intermittent nature of offshore wind will require some stabilisation mechanism, similar to the requirements for an electricity network
- Some industrial processes are batched so can facilitate an intermittent supply with lower levels of storage
- For larger continuous industrial processes a stable and predictable supply will be needed which will require significant amounts of storage to achieve
- For small amounts of storage surface tank farms are likely to suffice
- For larger storage, geological storage in salt caverns, saline aquifers or depleted oil and gas fields must be considered
- There are pros and cons of each of these that are beyond the scope of the study and our baseline assumption is that this has been available where it is needed for the economics and demand
- Clearly any hydrogen system will have to take reality into consideration when designing a route to market



Different types of electrolysers have different responses to their inputs – choosing the right type for the application will be key



Alkaline (ALK) and Proton Exchange Membrane (PEM) are the two most mature tech. Solid Oxide Electrolyser Cell (SOEC) still features a high TRL¹, while Anion Exchange Membrane (AEM) is currently under development

ALK, PEM, and AEM are low-temperature electrolysis process, which show between 60% and 67% efficiency. SOEC, as a high-temperature process, benefits from higher electrical efficiency, ranging up to 80%

Electrolysers are made of stacks, i.e. cells stacked one on another. Larger stack sizes can enable the scale up of electrolysers: ALK and PEM are expected to reach the 5 to 10 MW scale in the future

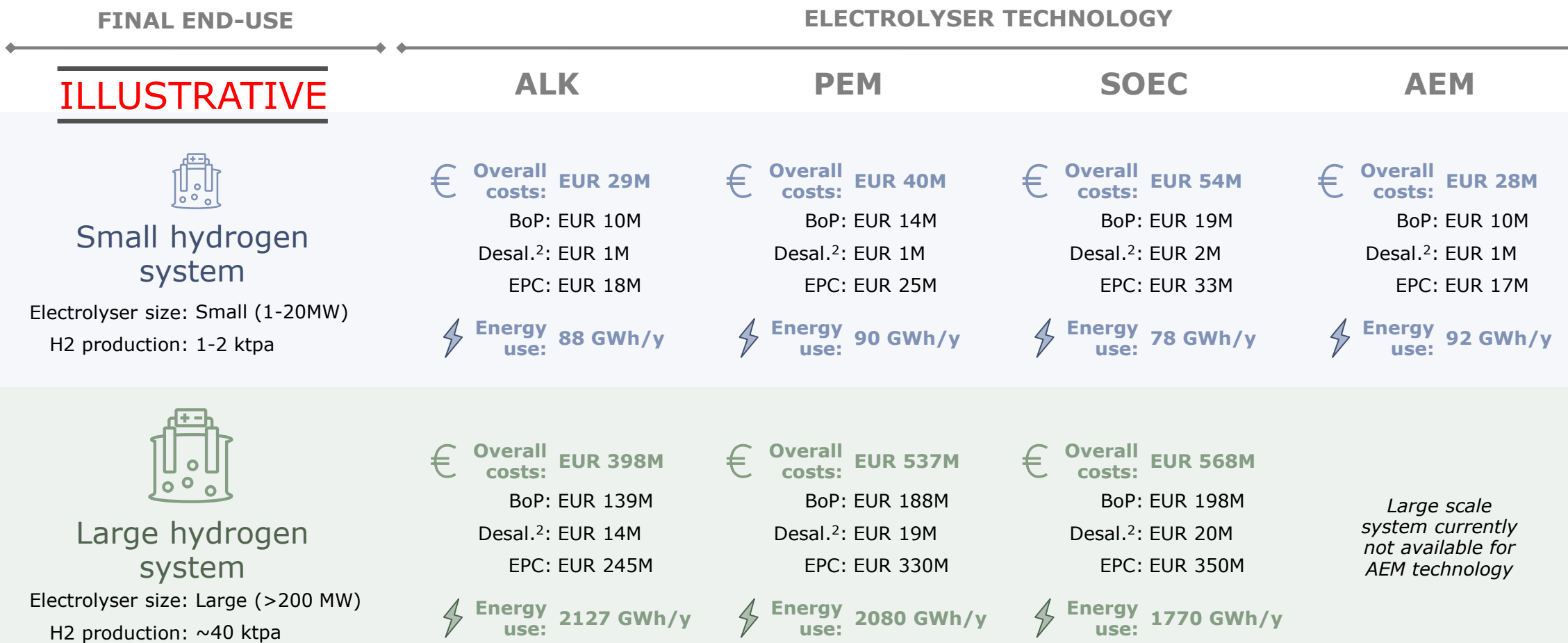
Fast response time and quick cold starts (<30min) make PEM particularly suitable to be coupled with flexible load sources, as PV. SOEC show the lowest flexibility, especially due to high cold start times (around 6 hours)

ALK and PEM are projected to exhibit more than 80'000 hours of equivalent full load hours. Today, AEM and SOEC show lower stack lifetime, that may improve thanks to enhanced material degradation properties

PEM and SOEC generally employ critical materials, as platinum group metals and Yttrium and Lanthanum, respectively³. At the other side of the spectrum, AEM typically use not critical – and less expensive – materials

Note: 1) Technology Readiness Level. 2) Values shown refer to equivalent full operating hours. 3) Actual materials may depend on manufacturer. 4) For quantitative benchmark see Annex 5.1

Building the required electrolysers to make use of the ORE may require a total investment cost between EUR 20-30 billion



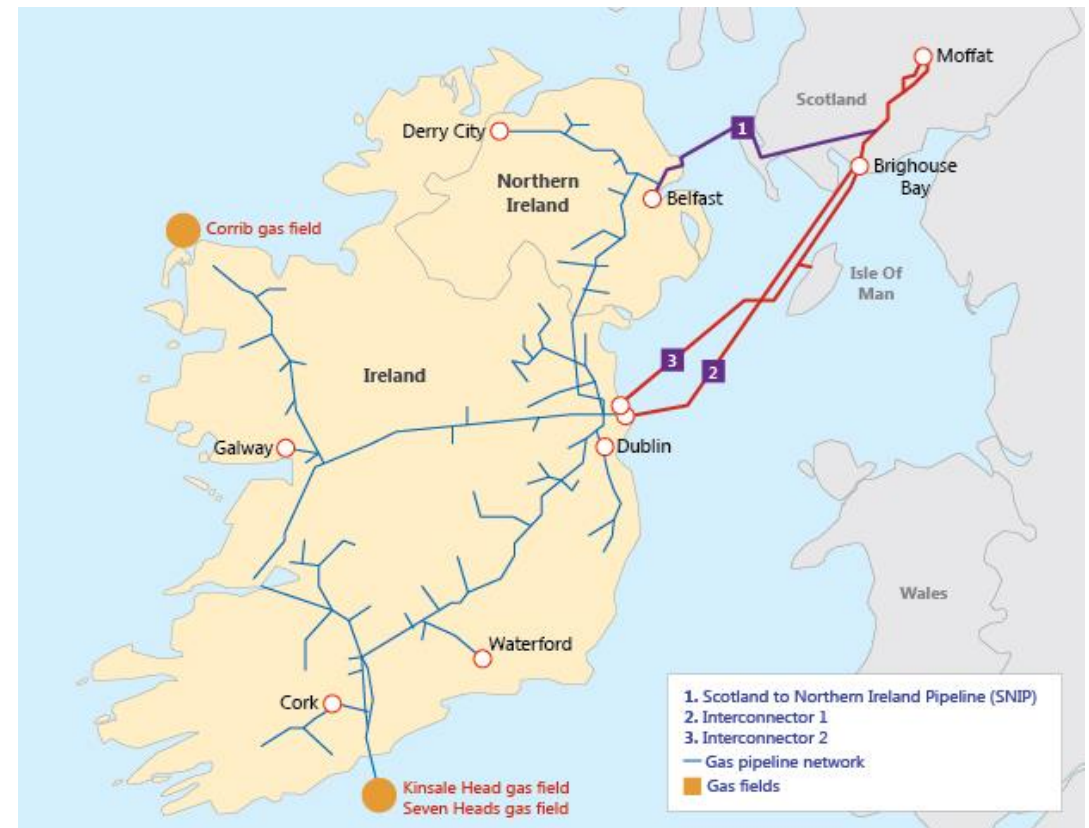
Note: 1) Costs and efficiencies as per 2025 data. 2) Assuming desalination is needed, for illustrative purposes.

A Hydrogen pipeline network will need to be established that connects the hubs and any export route will be via UK or with a long pipe to France

OVERVIEW

- After development of the electrolyzers and storage there would need to be development of a pipeline network to link the hubs with salt caverns and export routes
- It is likely that any hydrogen pipeline network would follow or reuse the existing domestic gas network
- Export routes from large volumes of hydrogen are best suited to transit the UK with a departure point in Dublin to land with HyNET
- There is significant risk in tying an export route to another countries infrastructure, not least due to phasing but a similar issue would be faced connecting into the European hydrogen backbone through France, Spain or Portugal
- Departure points in Cork or Waterford are likely to be the route for direct connection to the continent
- In addition for any large scale eSAF a connection to SWIC via Pembroke is likely to be required from Waterford to get CO2
- For any bunkering and export by ship the best candidates are likely to be the south coast or Shannon estuary

EXISTING INTERCONNECTIONS



There are a number of practical considerations to consider when deciding on a route to market via pipeline

Pipeline Length and route

The required export pipelines could span long distances and will require careful engineering and considerations for maintenance access. Onshore pipelines can often face local opposition and routing and RoW will be very important to get right

Submarine Pipeline Protection

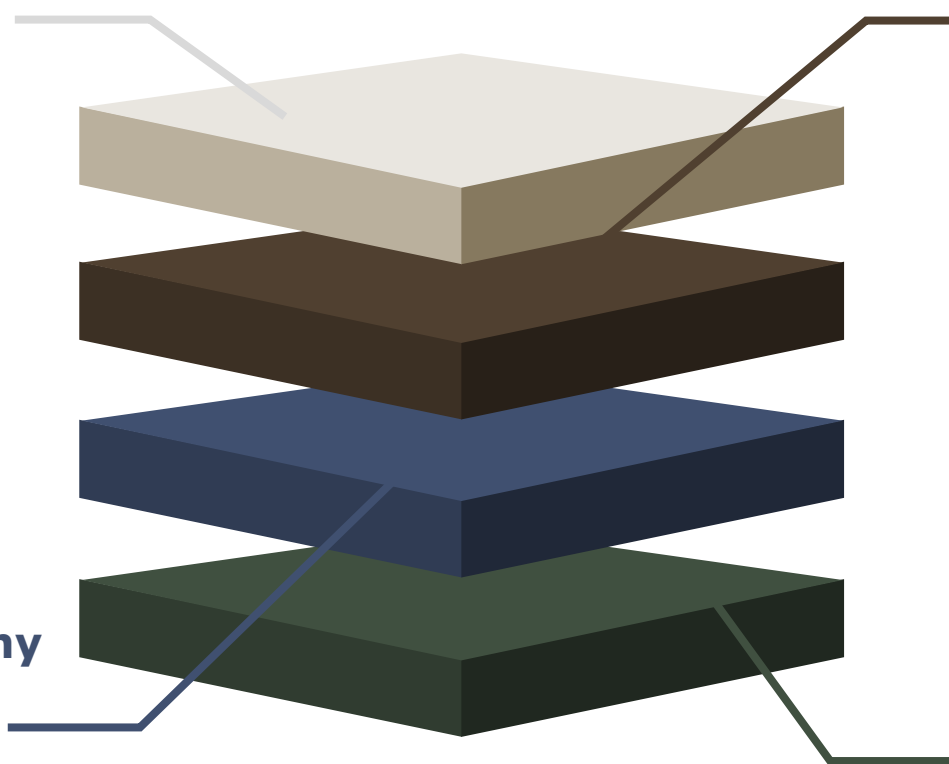
Protecting subsea pipelines from damage caused by factors such as ship anchors and fishing activities is imperative to maintain integrity and avoid leaks

Depth & Subsea Topography

Installing subsea pipelines involves specialized vessels and equipment. Laying pipelines on the seabed (or burying them), often at significant depths, requires careful planning and precise execution. Factors like seabed topography and existing infrastructure may complicate the installation process.

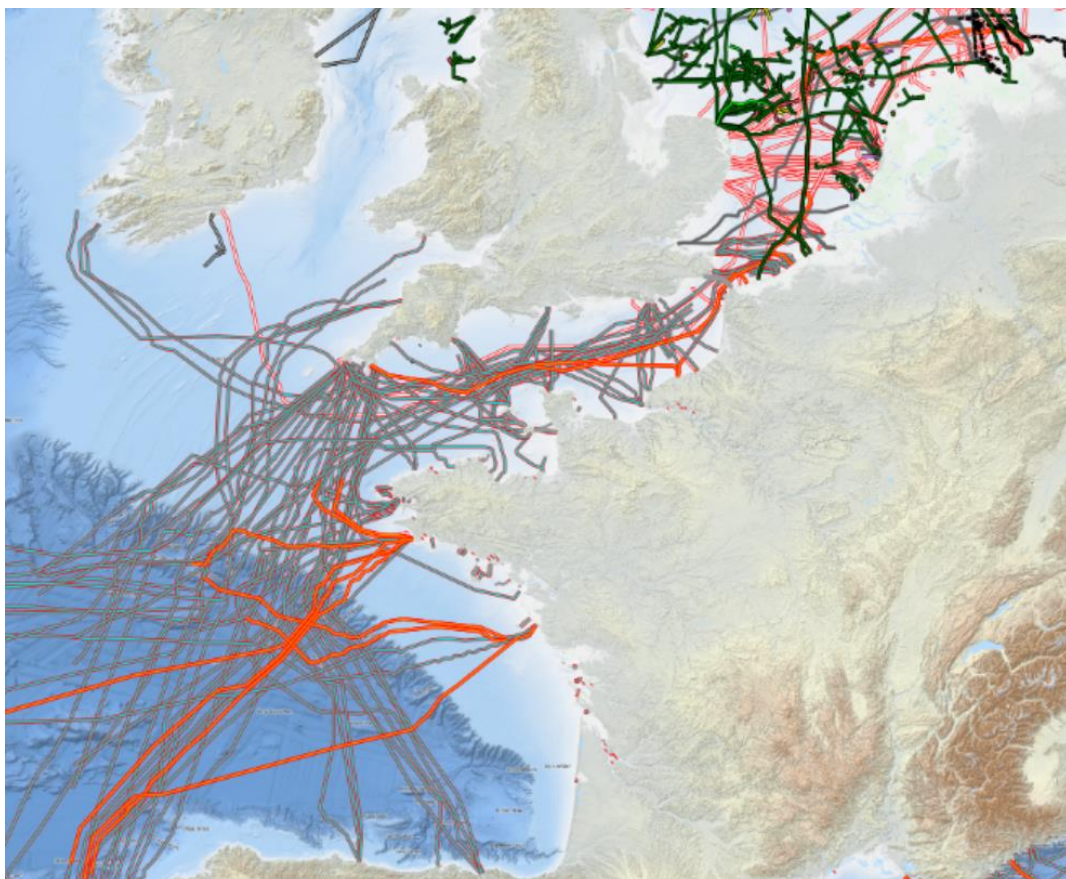
International Coordination

Coordinating with multiple countries, regulatory bodies, and stakeholders can add a layer of complexity in terms of permitting, regulatory compliance, and international agreements



Practical considerations such as pipeline routes can have a substantial impact on the feasibility and cost of the project similar to interconnectors

SEABED CONGESTION



Source: European Atlas of the Seas

COMMENTARY

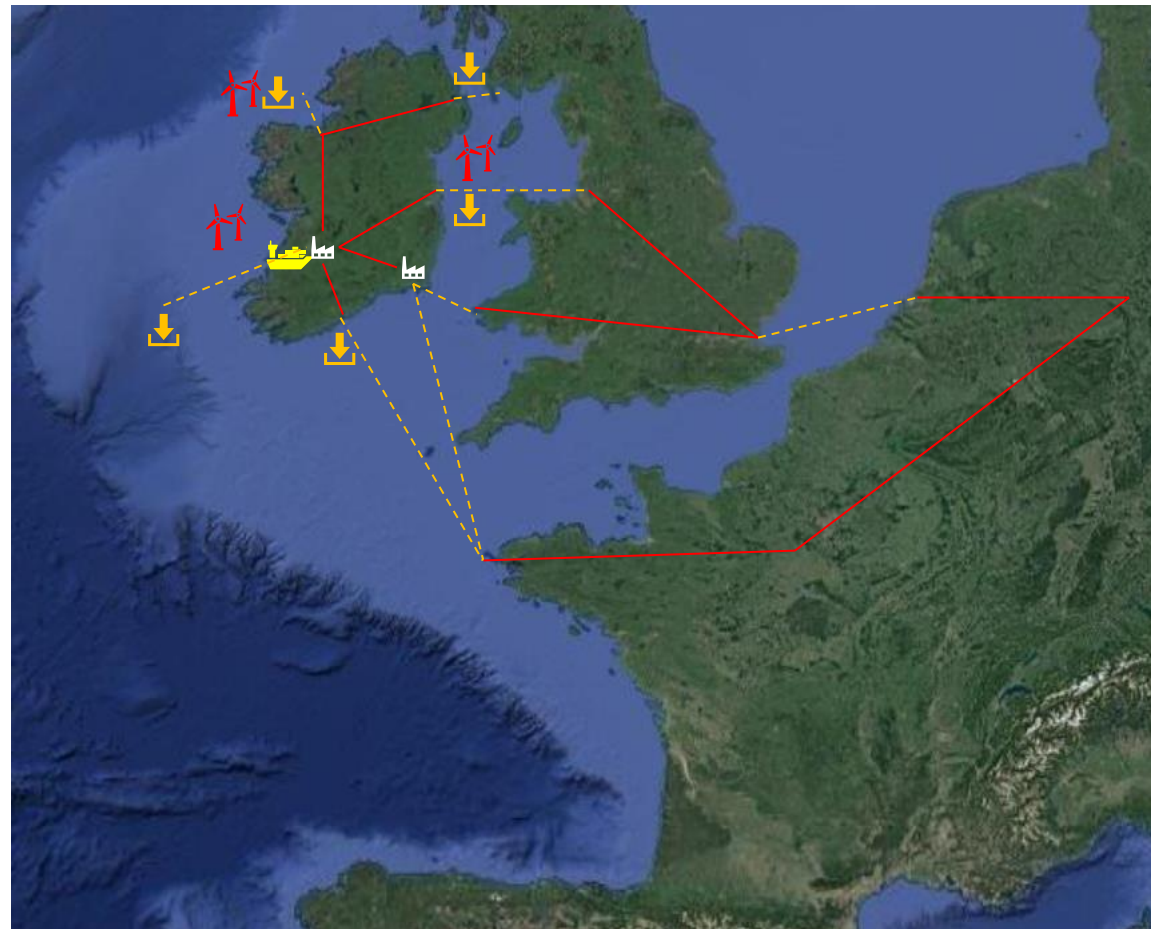
- As the gateway to the Atlantic the approaches to Ireland are extremely congested with existing infrastructure which will add costs to any pipeline projects
- Metocean, water depth and sea bed topography are also major concerns when planning any pipeline that would connect southern Ireland with France
- Careful consideration will need to be given to the cost and timing of pipeline construction – it is also worth noting that the hydrogen backbone in Europe is still not realised and could potentially mean the pipe would still not connect to demand centres
- Similarly UK infrastructure is likely to be on a long scale timeline which in the short term likely means that shipping options will be more practical
- Even on Ireland itself there has been a history of opposition to pipelines so community engagement and RoW works will need to be done well ahead of any planned projects

ROUTE TO MARKET

There are a number of credible routes to market and a detailed feasibility study would be required to select the best one

ILLUSTRATIVE SCHEMATIC OF A ROUTE TO MARKET

- Key hub locations would be linked by a N-S pipeline linking the west coast hubs with a number of spurs to connect to the east coast hubs across Ireland
- Large scale ammonia facility would make the most sense in the Shannon Estuary with a SAF facility best located around Waterford – both these plants would need to be on the 1Mt scale
- Two main export routes exist; via the UK through Benelux to Germany or via France to Germany in both cases this link up with the NW Europe market would mean all hydrogen could be absorbed
- The size of this pipeline would likely be a capacity of 20TWh



Route to market is not without risks and there are some key risks that need to be managed as part of the strategy

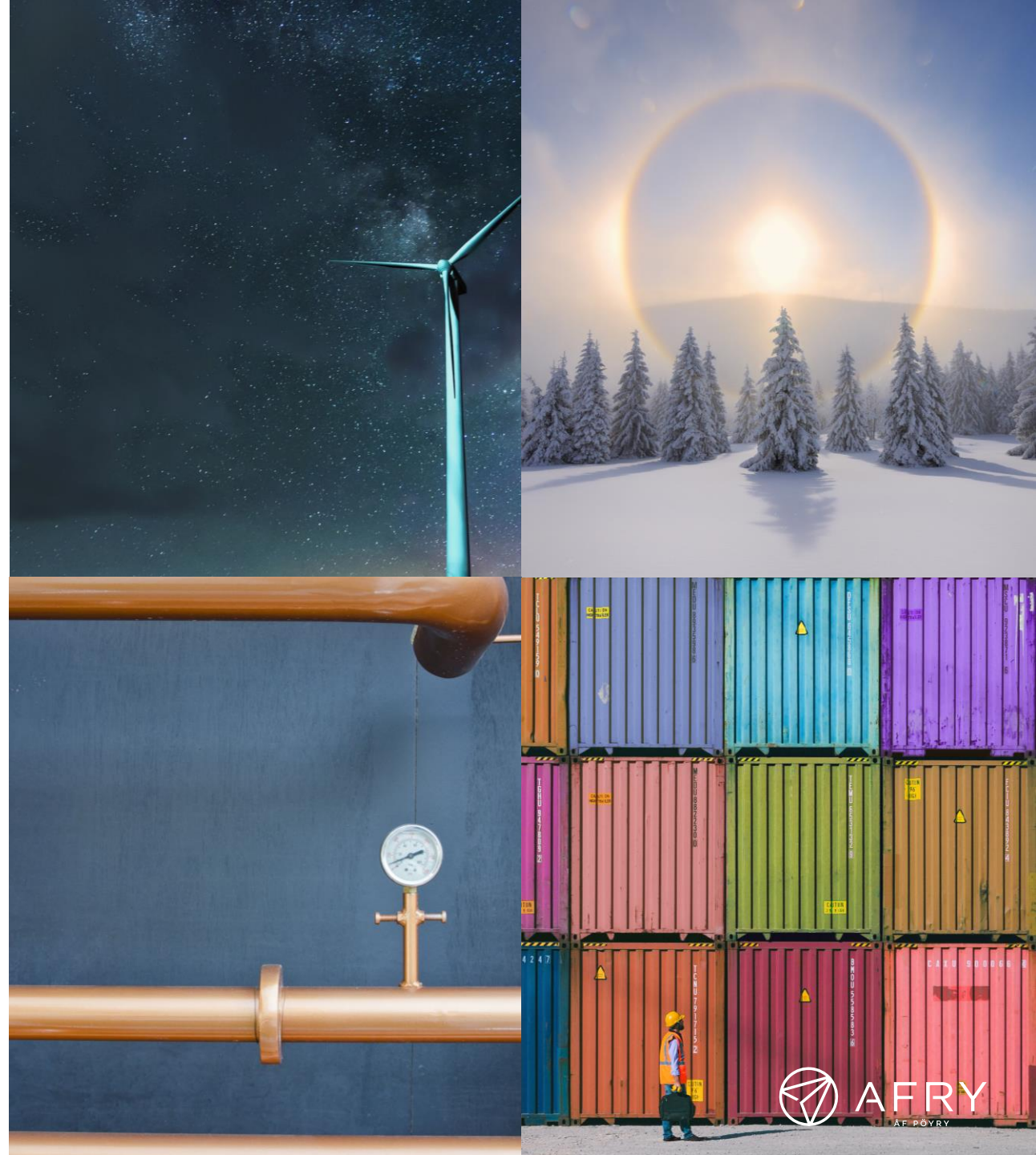
- Likely to be significant supply chain issues with construction and delivery of electrolyzers to meet the scale required against global competition and this likely means that project costs will rise
- Pipeline routing is challenging given the need to connect into a hub and the phasing of that infrastructure in Europe
- Scaling up a new industry in Ireland is likely to face skills and labour challenges which add costs and make such an industry uncompetitive
- The outlook for ammonia and derivatives is still uncertain as the demand as a maritime fuel as well as how fertiliser will be produced is still uncertain – danger that others could do the same thing cheaper so a potential need for first mover advantage
- The potential of eSAF is large but would require a dedicated carbon supply chain and infrastructure as it is unlikely that there is enough domestic emissions that could be captured to do it at the scale required



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9. Data tables

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Assumption for hydrogen demand projections

	Gradual decarbonisation scenario		Rapid decarbonisation scenario	
	2030	2050	2030	2050
Oil refining	Demand for oil products increases by 10% in comparison with 2021	Demand for oil products increases by 10% in comparison with 2021	Demand for oil products decreases by 19% in comparison with 2021	Demand for oil products decreases by 77% in comparison with 2021
Steel production	8% of future global steel production is DRI	30% of future global steel production is DRI	15% of future global steel production is DRI	70% of future global steel production is DRI
Road transport	0.1% of HDVs use fuel cell technology	5% of HDVs use fuel cell technology	2% of HDVs use fuel cell technology	30% of HDVs use fuel cell technology
Aviation	2% of aviation fuel is E-kerosene	20% of aviation fuel is E-kerosene	5% of aviation fuel is E-kerosene	50% of aviation fuel is E-kerosene
Maritime shipping	1% of marine fuel is ammonia	15% of marine fuel is ammonia	7.5% of marine fuel is ammonia	60% of marine fuel is ammonia
Electricity	Hydrogen constitutes 0.05% of the electricity generation mix	Hydrogen constitutes 0.5% of the electricity generation mix	Hydrogen constitutes 0.1% of the electricity generation mix	Hydrogen constitutes 1.5% of the electricity generation mix
Aluminum and cement production	1% of production use hydrogen for heating	20% of future global production use hydrogen for heating	8% of future global production use hydrogen for heating	85% of future global production use hydrogen for heating
Ammonia and methanol production	Chemicals production grows at the historical rates			