Scottish Enterprise

Assessment of Low-Carbon Hydrogen Supply Chain Export Opportunities

Final Report

May 2024

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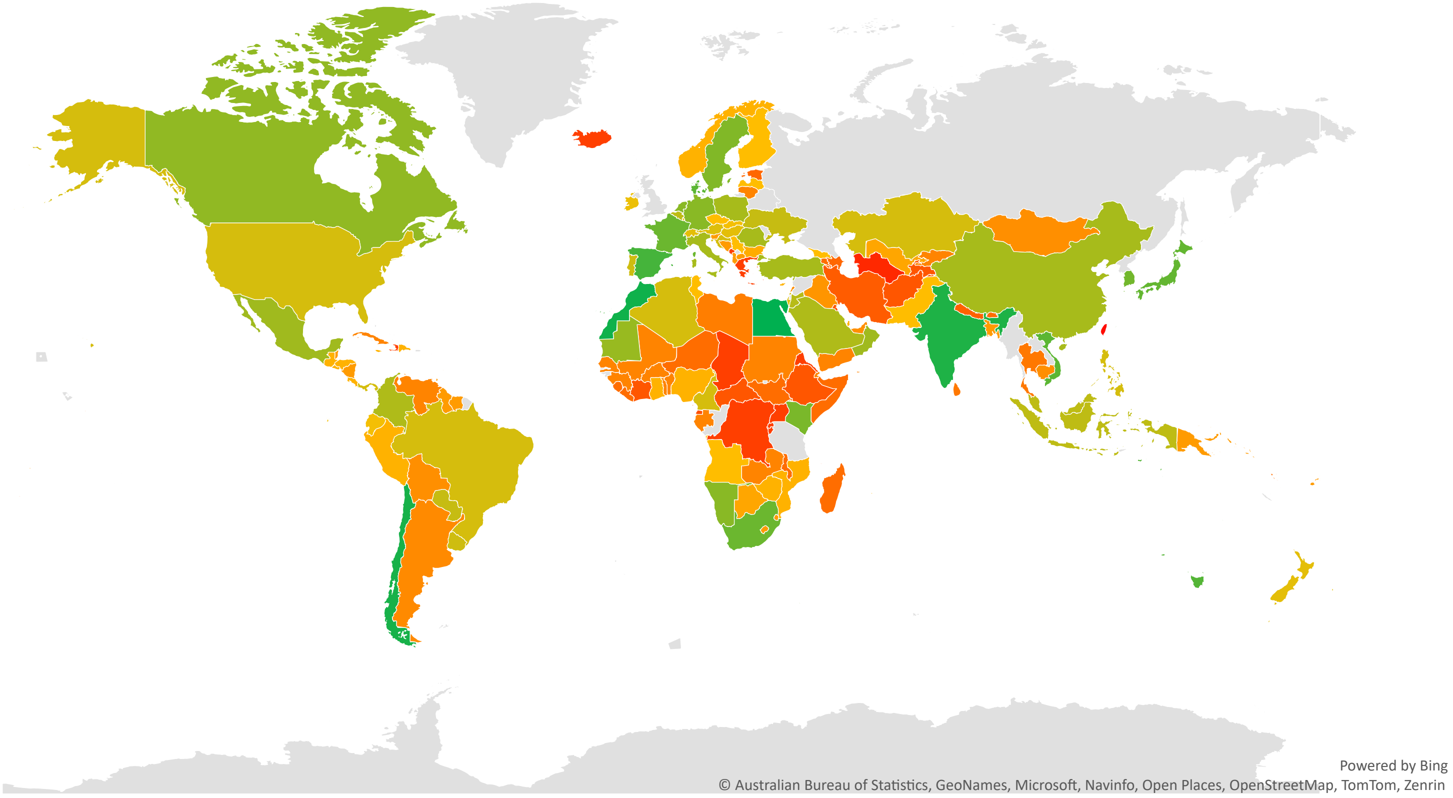
Executive Summary
Introduction

This report highlights the role that Scottish companies could play in the global hydrogen skills, materials and services market. It provides valuable insights and evidence that can help inform the development of Scottish Government's Hydrogen Sector Export Plan.

The report offers a high-level overview of the current hydrogen sector capabilities in Scotland, including the key products, solutions, and services in which Scotland has relevant expertise. Through engagement with Scottish Enterprise, and utilising specific sector knowledge, a list of companies in Scotland that have either established a role in the hydrogen sector, or identified a potential role, was created. This list provided an overview of Scotland's existing capability in the hydrogen sector and enabled the creation of a qualitative capability assessment for Scotland.

Following the assessment of Scotland's capabilities, 170 countries were compared through a multi-criteria analysis to identify those that offer the greatest supply chain business potential for Scottish companies. Assessment criteria of Ambition, Capability, and Alignment were used to evaluate the relative scale of opportunity, along with an understanding of Scotland's ability to capitalise on it.

The results of this analysis are mapped opposite and enabled the selection of five priority markets for deeper export opportunity evaluation.



Country scores from multi-criteria analysis displayed from green to red

Green indicates a country with high scores for ambition, capability and alignment

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Executive Summary
Findings

Scotland's Capabilities

- Scotland is well positioned to export supply chain capability and skills in the low-carbon hydrogen sector, with 1,000+ companies already exposed to the sector delivering products, solutions, and services across the supply chain.
- Case studies of five companies already exporting hydrogen services and skills are presented, showing the breadth of Scottish expertise in the hydrogen sector.
- Scotland's strengths include hydrogen production, hydrogen mobility applications, cross cutting services such as project development and operations & maintenance, along with cross cutting products, such as process and electrical equipment.
- Future work should focus on determining in more detail the sectors that Scotland has a clear advantage in and highlighting those companies that could be supported to export.

Market Prioritisation and Assessment

- Egypt, Chile, India, Australia, Spain and Morocco were identified as priority markets primarily driven by the size and scale of their hydrogen ambition, perceived likelihood of a gap in their domestic capabilities, and Scotland's ability to capitalise on the opportunity.
- Along with identifying priority markets, the assessment has built an evidence base to enable further analysis and support decision making.
- Future work could focus on the sensitivity analysis performed to identify countries that may have close links to Scotland but who scored poorly due to one metric, for example the USA.

Egypt

- Egypt have a combination of significant ambition, limited internal capability, and strong alignment with Scotland. Their planned target of 1.4GW of green hydrogen by 2030 makes them a good target for Scottish companies. However, it is likely that local partners would be required in Egypt, so engagement is important to secure those links.

Chile

- Chile scored very highly in the analysis due to high ambition and strong alignment. There is greater in-country capability in Chile but there are still significant gaps that Scottish companies could fill. Chile's huge targets and export potential make it appealing but there remain several challenges and risks associated with the development of hydrogen in Chile, including economic uncertainty and water scarcity.

India

- India had the highest ambition score due to their strong, policy backed targets. Currently they have limited but rapidly growing capability. The Indian government is focused on ensuring local content within the delivery of hydrogen projects and therefore this may pose a challenge for Scottish companies to achieve market entry. Early engagement with the Indian sector will be important to allow Scottish companies the opportunity to work on their projects.

Australia

- Australia scored very highly in ambition and alignment but had a lower capability score. Australia is advanced in developing its hydrogen sector in comparison to many other nations. However, the scale of the targets and economic opportunity mean that possibilities remain for Scottish companies. One of the primary issues with entry into the Australian market is simply the distance, as it is likely offices or manufacturing facilities would be better established in-country rather than exporting from Scotland.

Spain and Morocco

- Spain and Morocco's hydrogen markets are likely to be heavily linked due to their geographical proximity, high ambitions and alignment with both each other and with Scotland. Spain is expanding domestic electrolyser manufacturing capacity but opportunities exist in the supply chain for sub-components. Proposals for large-scale pipeline distribution systems across Spain represent an opportunity for Scotland to leverage oil & gas pipeline planning and construction experience. Whilst it's likely that significant domestic capability will be employed in supporting many Spanish projects, opportunities remain to export services such as system integration and Engineering, Procurement and Construction (EPC).

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Contents

Nomenclature

Abbreviations

CNG	Compressed Natural Gas
COP	Conference of Parties
EPC	Engineering, Procurement, and Construction
EU	European Union
GDP	Gross Domestic Product
GVA	Gross Value Added
HACI	Hydrogen Adjacent Capability Index
HSEP	Hydrogen Sector Export Plan
IVA	Industrial Value Added
ktpa	Kilo Tonnes per Annum
MAI	Market Alignment Index
MCA	Multi-Criteria Analysis
Mtpa	Million Tonnes per Annum
OEM	Original Equipment Manufacturer
PCI	Prodcutive Capacities Index
R&D	Research and Development
SMR	Steam Methane Reforming
UK	United Kingdom
US	United States

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Section 1

Introduction

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1.1. Background
Introduction to study

Scotland is well placed to become a leader in the low-carbon hydrogen sector, with significant renewable resources, strong oil and gas sector experience, and supportive government policy. In 2020, the Scottish Government published the Hydrogen Policy Statement outlining this ambition with aims for 5 GW of installed capacity by 2030 and 25 GW by 2045. This was built on by the Scottish Hydrogen Assessment (2020) that noted the value Scotland could capture from the sector through innovation, manufacturing, and infrastructure. Steps for delivery of this ambition were set out in the Hydrogen Action Plan (2022), which also noted the potential for the export of skills and services.

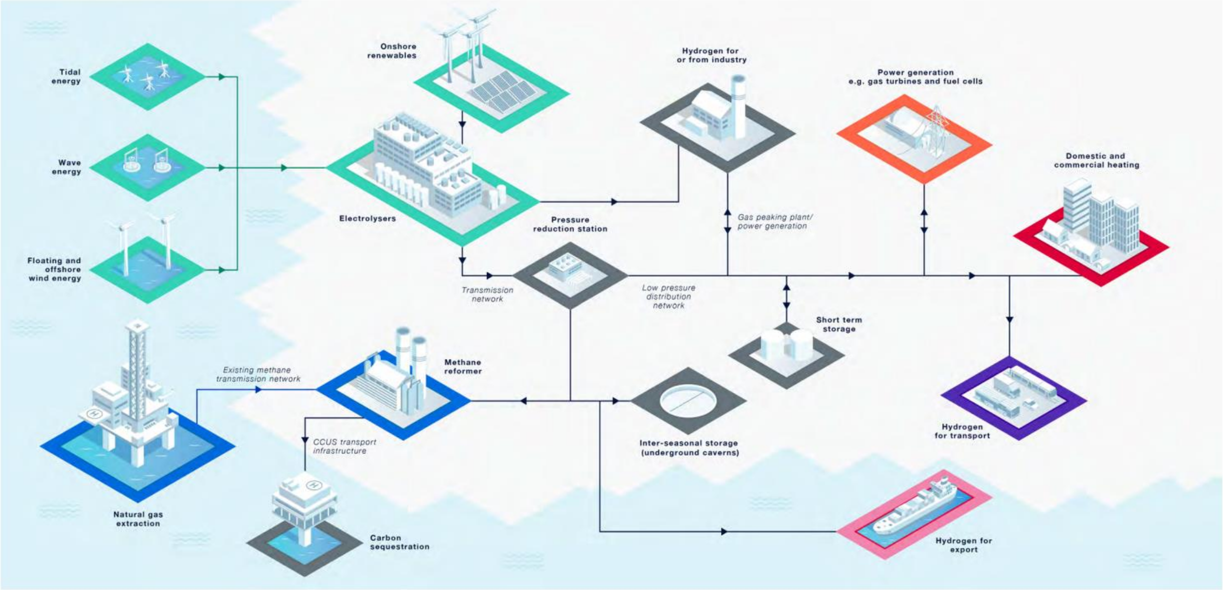
Scotland's leadership and early growth in the low-carbon hydrogen sector enables opportunities to export skills, capability, and expertise to emerging markets. In 2019, Scottish Government published A Trading Nation: A Plan for Growing Scotland's Exports to set out a strategic approach for growing exports to deliver economic benefit. A series of Sector Export Plans are being developed to deliver this ambition and contribute to the National Strategy for Economic Transformation, including the Hydrogen Sector Export Plan (HSEP). This study aims to contribute to the development of the HSEP.

The objective of this study is to deliver an assessment of global hydrogen markets to identify, investigate, and evaluate opportunities for Scottish companies to export capability across the low-carbon hydrogen supply chain. This work will build on previous publications from the Scottish Government and support the development of the HSEP. Our approach focuses on three core pieces of work to build a strong understanding of the opportunities for Scotland and an evidence base to enable further analysis and support decision making.

- Scotland’s Capabilities: a high-level review of Scotland’s hydrogen capabilities to help match Scotland's strengths to potential export opportunities.
- Market Prioritisation: identification of markets that represent the greatest hydrogen export potential for Scotland.
- Priority Market Assessment: investigation and evaluation of the Priority Markets to deliver a deeper understanding of export opportunities and challenges.

This study has been delivered with continued collaboration from the project steering group, comprising of representatives from Scottish Enterprise, Scottish Development International, and Scottish Government. This has supported delivery of work that closely aligns with their priorities.

This study concludes with recommendations that will enable further analysis on priorities identified, to support the development of HSEP and the wider Scottish hydrogen export strategy.



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1.2. Global Outlook

Overview of the current global hydrogen markets

Pipeline

The global hydrogen industry is currently going through a period of significant growth and momentum. The global pipeline of announced low-carbon hydrogen projects in 2023 equates to 174 million tonnes per annum (Mtpa)[1]. Current global low carbon hydrogen operational capacity is approximately 800 kilo tonnes per annum (ktpa)[2], which is less than 1% of the hydrogen produced from fossil fuel sources. A further 3 Mtpa of low carbon hydrogen capacity has passed Financial Investment Decision (FID)[2]. Therefore, the scale of the pipeline will require considerable investment in the supply chain to practically deliver these projects and ensure the current interest in the hydrogen sector is capitalised on.

Hydrogen demand is generally growing more slowly than the production pipeline, and securing offtakers is a key challenge for many projects. The largest demand sectors are currently industrial (e.g. ammonia, refining, steel) and maritime, with some growth in power, transport and aviation sectors.

Markets

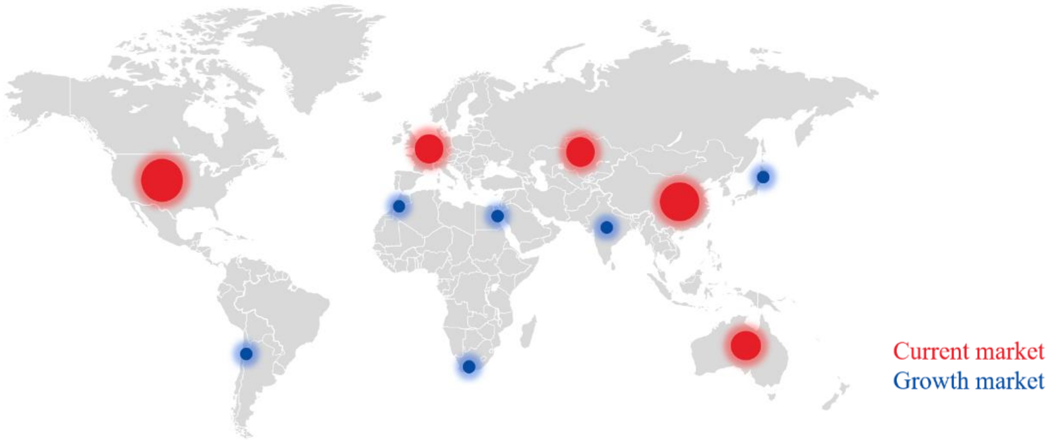
North America has the largest volume of low-carbon hydrogen production passed FID, with demand driven largely by ammonia production and refining. This is followed by China, which has several large scale (>100 MW) projects committed, then Australia, Kazakhstan and Europe. The US is also the largest market for blue hydrogen with 39% of global capacity[2]. Although many of the planned low carbon hydrogen projects are in Europe and the US, where incentives are the strongest, China currently has the largest share of manufacturing capacity. Other growth markets include Middle East and Africa (including Saudi Arabia, which has committed to giga-scale green hydrogen projects, Egypt and Mauritania) and Latin America which has a significant project pipeline but is yet to commit to large scale projects.

Supply Chain

Timing the scaling of the hydrogen supply chain in line with production targets and demand is key challenge for the growing hydrogen industry. While on paper electrolyser manufacturing capacity is outpacing demand, many European and US developers avoid Chinese equipment (due to quality and bankability concerns), leading to longer lead times in those markets[1]. Potential supply chain gaps could include availability of materials and technology, skilled labour (such as EPC and integrators) and project build-out experience.

Policy Support

The low carbon hydrogen sector will require government support to stimulate demand and reduce risk associated with early-stage projects. As of October 2023, fifty-two countries globally have hydrogen strategies in place with accompanying production and demand targets. Government funding for hydrogen projects is most prevalent in Europe and the US through mechanisms such as the EU Innovation Fund and Inflation Reduction Act tax credits.



Global low carbon hydrogen production capacity hotspots

1. BNEF 2H 2023 Hydrogen Market Outlook (Oct 2023)
2. Hydrogen Council Hydrogen Insights 2023 https://hydrogencouncil.com/wp-content/uploads/2023/05/Hydrogen-Insights-2023.pdf

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1.3. The Low Carbon Hydrogen Supply Chain
Segments and Capabilities

To assess the opportunities for Scotland to export supply chain capabilities, the supply chain model below was used to break down the supply chain into the key segments of the hydrogen lifecycle including production, distribution, storage, and use. For each of these segments, supply chain capabilities were identified across products, services and solutions.

Production
Producing low-carbon hydrogen using electrolysis or CCS-enabled thermochemical.

Distibution
Delivering hydrogen from production to storage or end-use.

Storage
Storing hydrogen to help balance supply and demand.

Use & Offtake
Using hydrogen across a range of sectors, including production of derivatives.

Products
Physical elements within the supply chain, such as an electrolyser, compressor, or electrical equipment.

Solutions
Capabilities that directly deliver products, such as manufacturing, construction, or integration capability.

Services
Auxiliary capabilities that support the delivery of products, such as engineering, environmental, operations & maintenance or financial services.

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Section 2

Scotland's Capabilities

2. Scotland's Capabilities
Hydrogen Supply Chain

Company data

The first aspect of this study was to provide a high-level review of Scotland's capabilities across the low-carbon hydrogen supply chain. Data relating to Scottish companies was evaluated to highlight the products, solutions, and services that the Scottish market can offer.

Company data was primarily provided by Scottish Enterprise and then augmented by Arup's experience in the sector, along with additional data sources, such as Innovate UK. The sample included over 1,200 companies with information relating to their level of exposure to low-carbon hydrogen and primary goods or services offering. This information was processed and categorised into common capabilities (e.g., process equipment or project management) across products, solutions, and services. Companies included in the sample has some level of exposure to low-carbon hydrogen; hence, the review is not comprehensive and number of companies operating in the sector are likely to change frequently.

Carbon Capture and Storage (CCS) associated with fossil-fuel derived hydrogen production (Blue Hydrogen) is an area that has obvious parallels with Scotland's oil & gas expertise. Although skills and services including geology, drilling and sub-surface equipment are not specifically highlighted in this report, they will often be a subset of capabilities provided by many of the oil and gas companies included in the analysis.

Presented on page 13 is the number of companies providing a specific product, solution, or service relevant to the hydrogen market. This shows that Scotland's current offering within the market centres around products and services. A large number of companies manufacture equipment and components that are directly applicable to the supply chain – primarily within the process industry. While there are a smaller number of solution-oriented companies, this area is strengthened by several highly experienced project developers.

Presented on page 14 is the number of companies by capability type and their maturity within the low carbon hydrogen sector. This shows that the majority of Scotland's hydrogen sector is still emerging into the market, which is consistent with a nascent sector such as low carbon hydrogen. However, there are a few Scottish companies that have an established presence within the sector. This shows that while Scotland's hydrogen sector is still at an early stage, it is becoming more mature, placing it in a competitive position to export products, solutions, and services to other markets.

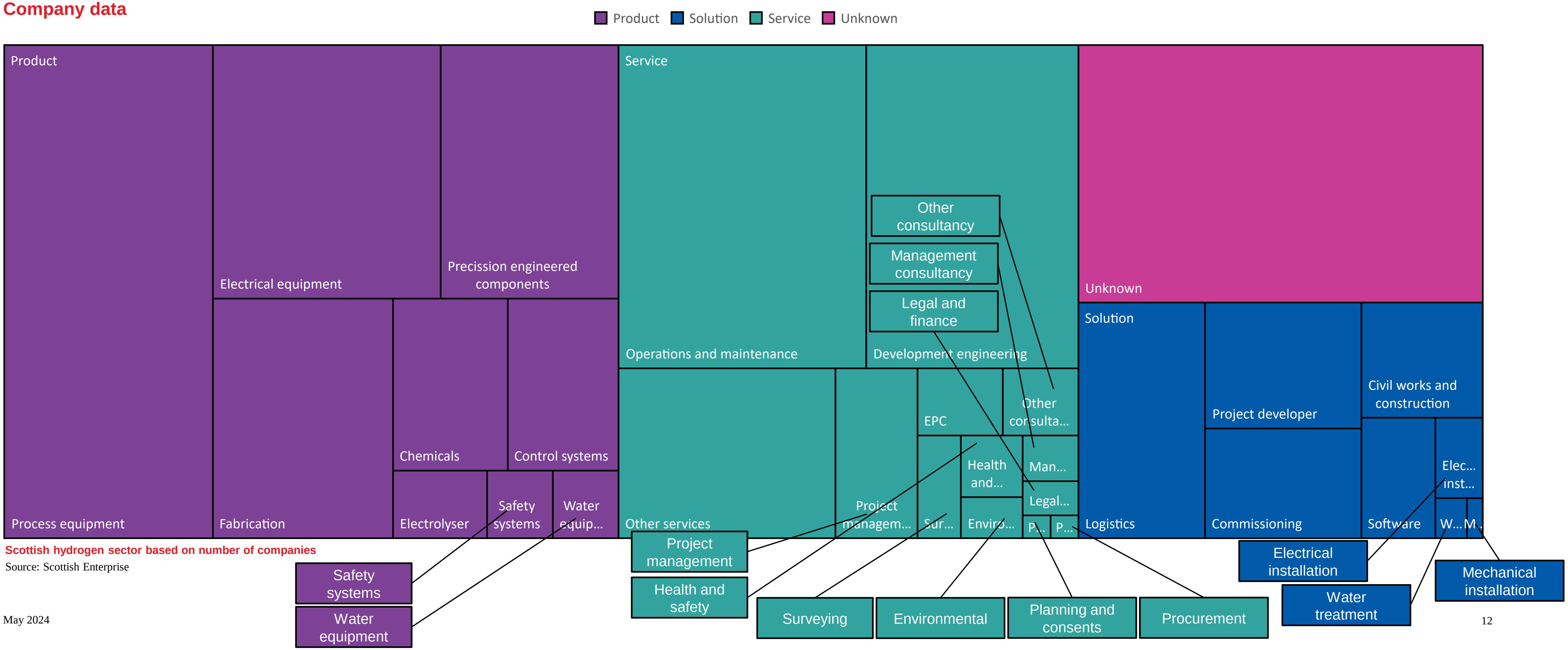
There are over 1,000 Scottish companies with some level of exposure to the hydrogen sector that provide products, solutions, and services across the supply chain. This suggests a lot of possibilities for export and that Scotland is well positioned to capitalise on emerging opportunities in low-carbon hydrogen.

Scottish companies mapped by capability

Source: Scottish Enterprise

2. Scotland's Capabilities
Hydrogen Supply Chain

Company data



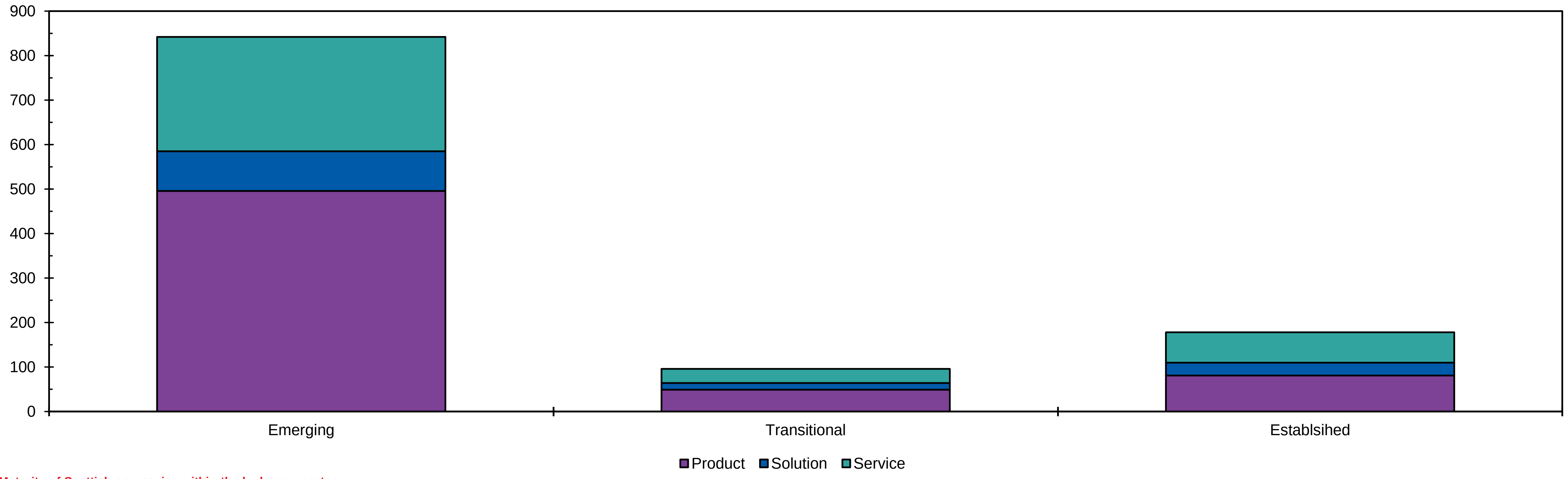
Scottish hydrogen sector based on number of companies

Source: Scottish Enterprise

2. Scotland's Capabilities
Hydrogen Supply Chain

Company data

Number of Scottish companies by hydrogen maturity and capability type



Maturity of Scottish companies within the hydrogen sector

Source: Scottish Enterprise and Arup assessment.

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2. Scotland's Capabilities
Hydrogen Supply Chain

Qualitative rating

Based on the company data and a wider understanding of the sector, Scotland's capabilities (i.e., products, solutions, services) were qualitatively assessed and mapped to supply chain segments (i.e., production, distribution, storage, use). The outcomes of this assessment will feed into more detailed analysis in the Market Prioritisation to help match opportunities to Scotland's strengths, helping to assess Scotland's ability to capitalise on opportunities.

The outcome of this assessment is presented opposite. Segments were rated high (H), medium (M), or low (L). These ratings represent Scotland's capability compared to the current state of the global market. A dash (-) indicates that that segment has not been scored due to a lack of information. Therefore, a high rating means that they have comparably good expertise in a particular segment. A low rating means there has been limited work in this area in Scotland compared to the other segments.

Capability within hydrogen production was rated highly. This was driven by the large volume of equipment manufacturers that produce products directly relevant to this segment, primarily process and electrical. This is in conjunction with experience delivering a number of demonstrator projects in this area.

Hydrogen use in transport is another strength. This is due to the number of demonstrator projects that Scotland has in the area, along with substantial experience with hydrogen refuelling stations.

Under cross-cutting segments, project development is a clear strength of the Scottish market. There are number of project developers, currently operating in Scotland, that have an established presence in the hydrogen market. This is in conjunction with a strong services offering, including development engineering and project management, that range in hydrogen market maturity. Operation was also scored highly, primarily driven by the large number of companies offering operation and maintenance services.

Production		Distribution		Storage		Use		Cross-cutting	
Green	H	Pipeline	H	Pressurised	H	Industry	M	Development	H
Blue	H	Road	-	Liquid	-	Transport	H	Execution	M
		Rail	-	Solid	-	Power	L	Operation	H
		Shipping	-	Geological	-	Buildings	M		

Section 2.1.

Scottish Supply Chain Exporting Case Studies

2.1. Case Studies
Purpose

Scotland's hydrogen capabilities are best explored by engaging with the companies that are active in it. Through this engagement, it is clear that Scotland's supply chain are already actively engaged in exporting hydrogen services and skills to global markets. This includes exporting manufactured products, supporting new projects and offering integration services around the world. There are many great examples of Scotland leading the way in developing these skills and then utilising them to help other countries develop their hydrogen economies. This section describes five companies in Scotland that are already on this journey:

- Langfields,
- Hydrasun,
- Howden,
- Logan Energy, and
- EMEC.

Each company's reason for entering the hydrogen supply chain is different but all have either experience in developing or manufacturing hydrogen systems in Scotland. They have been at the forefront of Scotland's export ambitions in hydrogen, some for well over a decade.

These studies offer an example to other Scottish companies who may be transitioning towards low carbon hydrogen. Some of these companies remain active in the oil and gas sectors but are expanding their hydrogen operations significantly to support decarbonisation. The case studies speak to innovative, world leading hydrogen system integrators and cutting-edge research into the deployment of hydrogen around the world. The paths that these companies travel along could be used as a blueprint for further Scottish companies who wish to expand to support the growing hydrogen market.

LANGFIELDS

hydrasun

Howden
A Chart Industries Company

Logan Energy
hydrogen technologies

EMEC
THE EUROPEAN MARINE ENERGY CENTRE LTD

2.1. Case Studies
Langfields

Langfields are a design and manufacturing company that provides products across a range of sectors including hydrogen. They offer a large number of services including equipment design, workshop manufacture and site installation. Established in 1908, they have several large manufacturing locations around Scotland including Dunfermline and Caithness. They operate in various aspects of the hydrogen supply chain including electrolytic production, steam methane reforming and carbon capture, utilisation and storage.

Langfields have worked to support the electrolyser manufacturing industry since 2019. They produce several internal components for different chemistries of electrolyser including some that are in the early stages of development. These components are exported around the world to different electrolyser manufacturing facilities. This experience extends to designing, manufacturing and installing critical pipework and vessels for a variety of different processes within the hydrogen sector. Additionally, their manufacturing facilities have produced large scale hydrogen storage vessels for use in projects around the world. This is identified as a key challenge to the hydrogen sector going forward as Langfields estimate existing public hydrogen projects will need an order of magnitude more vessels than can currently be manufactured.

Looking forward, Langfields see themselves growing their export market and providing a significant amount of manufactured goods from Scotland to hydrogen projects around the world. This includes both green and blue projects as their key products are required for both types of production. They see hydrogen as a significant area of growth over the next ten years.

Manufactured pressure vessel

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2.1. Case Studies
Hydrasun Limited

Hydrasun Limited provide high pressure gas system solutions for safety critical applications, originally supplying the Oil and Gas sector. Established in 1976, and headquartered in Aberdeen, they have developed their hydrogen systems knowledge and capability over the last decade.

Early success was achieved by supporting flagship hydrogen projects within Scotland, such as the Levenmouth Community Energy Project, the Big Hit and Surf and Turf projects in Orkney, and has since expanded to supporting projects around the UK and Europe.

Through the delivery of multiple projects, Hydrasun have developed specialist hydrogen system integration expertise and developed turnkey hydrogen refuelling station solutions that are scalable for different applications across the transport sector.

With established facilities in Aberdeen, Aviemore and Glasgow, they operate in other locations across the UK, The Netherlands and Germany.

Hydrasun has delivered over thirty projects covering engineering design, system integration, installation and commissioning and in-field support services to mobile and static hydrogen refuelling stations with and without on-site production across the UK, Scandinavia, and Europe.

They are currently in the process of developing their mid-scale packaged refueller solutions, which has the potential to support larger fleets around the world as they grow. This is supported by the recent acquisition of Fuel Cell Systems has extended their export capability to include hydrogen refuelling solutions to projects in Spain, France, Estonia and Slovakia.

Over the next decade, Hydrasun sees the hydrogen sector as a significantly growth sector for their systems with further expansion into Australia and USA.

BMW hydrogen vehicle refuelling in Sweden using Hydrasun’s mobile refueller

2.1. Case Studies
Howden

Howden, originally established in Glasgow over 160 years ago, is a leading global provider of mission critical air and gas handling products. Recently acquired by Chart Industries, the combined business has a proven track record supplying critical equipment across both the liquid and gaseous hydrogen value chains for projects across the globe. Principal Howden manufactured products include compressors, fans, steam turbines and other air and gas handling equipment. This portfolio and the addition of Chart’s complementary cryogenic products places Howden in an integral role in the hydrogen economy working across production, both green and blue, transportation, storage and utilisation with on-going projects across that range.

Howden has been exporting into the hydrogen sector globally for over 100 years and are at the forefront of several recent global hydrogen firsts, including supporting the world's largest hydrogen refuelling station in China, the world’s first climate neutral fuels facility in Chile and world’s largest hydrogen compression facility in Kuwait. The company is an active member of several global and regional hydrogen associations.

The site in Glasgow has cemented its position as head office for Chart and Howdens activities across EMEA. The technology manufactured in Scotland, although currently only applicable for select hydrogen applications, is expected to play an increasing role in hydrogen exports in the future as Howden strive to be a global leader in the Hydrogen market.

Containerised diaphragm compressor

2.1. Case Studies

Logan Energy

Logan Energy has over 25 years' experience in delivering projects in the low carbon, renewable energy, and hydrogen sectors. Based in Scotland and the Netherlands, they specialise in the delivery of integrated engineering solutions incorporating hydrogen technologies such as hydrogen production, refuelling stations, compression, storage, distribution, in addition to stationary, mobile, and on-vehicle fuel cell electricity and heat generation. Logan Energy are an independent manufacturer and select appropriate equipment to deliver hydrogen-based energy and technology projects. Operating out of Wallyford, they work with a network of suppliers to design, assemble and test all the equipment prior to deployment.

Logan Energy have been exporting hydrogen solutions to Europe and beyond for over ten years. They have deployed various hydrogen systems in the UK, Germany, France, The Netherlands, Spain and delivered a hydrogen refuelling station to China. These projects include:

- The delivery of a large capacity refuelling station for bus depots and logistics sites;
- The development of production and refuelling stations linked together on one site;
- Mobile hydrogen refuelling systems that can be used for multiple applications including purging and refuelling; and
- Tube trailer filling systems to allow larger production sites to deliver hydrogen to multiple smaller users.
- Delivery of integrated energy storage with renewable electricity generation including energy management systems

As an export champion for Scotland, Logan Energy intend to continue developing and delivery solutions for markets within Europe and Asia and are expanding opportunities in the Americas, Australasia and the Middle East. In addition, they have developed, and continue to develop, solutions to fill key market gaps in the existing global supply chain to increase exports to the global hydrogen market.

Various Logan Energy solutions deployed around the UK and in Europe

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2.1. Case Studies
EMEC

Established in 2003, the European Marine Energy Centre (EMEC) Ltd is the world’s first and leading facility for demonstrating and testing marine energy devices by providing open sea performance testing facilities.

EMEC is also pioneering research and development in green hydrogen and low carbon energy systems. In 2017, EMEC generated the world's first hydrogen from tidal power. Within the hydrogen sector, EMEC’s strategic areas of hydrogen research and development projects support renewables integration, maritime decarbonisation and aviation decarbonisation. On the aviation front, they have played a key role in projects such as HyFlyer with international partners. At European level, EMEC has collaborated on innovative hydrogen pilot projects including Surf’n’Turf, BIG HIT and ITEG. These projects were developed utilising close links to the European hydrogen market with key suppliers and partners coming from France, Spain, and the Netherlands.

As an early adopter of green hydrogen production and end use applications, EMEC has gained key insights into operations and maintenance of these assets and use this experience to facilitate knowledge sharing with those in the sector seeking to follow with their own hydrogen innovation. In European projects such as HEAVENN and Green Hysland, which are exploring how hydrogen can be used regionally to support the decarbonisation of the energy system, EMEC play an advisory role feeding in lessons learnt across areas including technology, regulation and socio-economics to help others develop roadmaps.

EMEC aims to continue to export their knowledge within the hydrogen sector globally and develop further demonstration projects around hydrogen and hydrogen-based synthetic fuels that will support the world in decarbonising the marine and aviation sectors.

EMEC refuelling hydrogen aircraft

Section 3

Market Prioritisation

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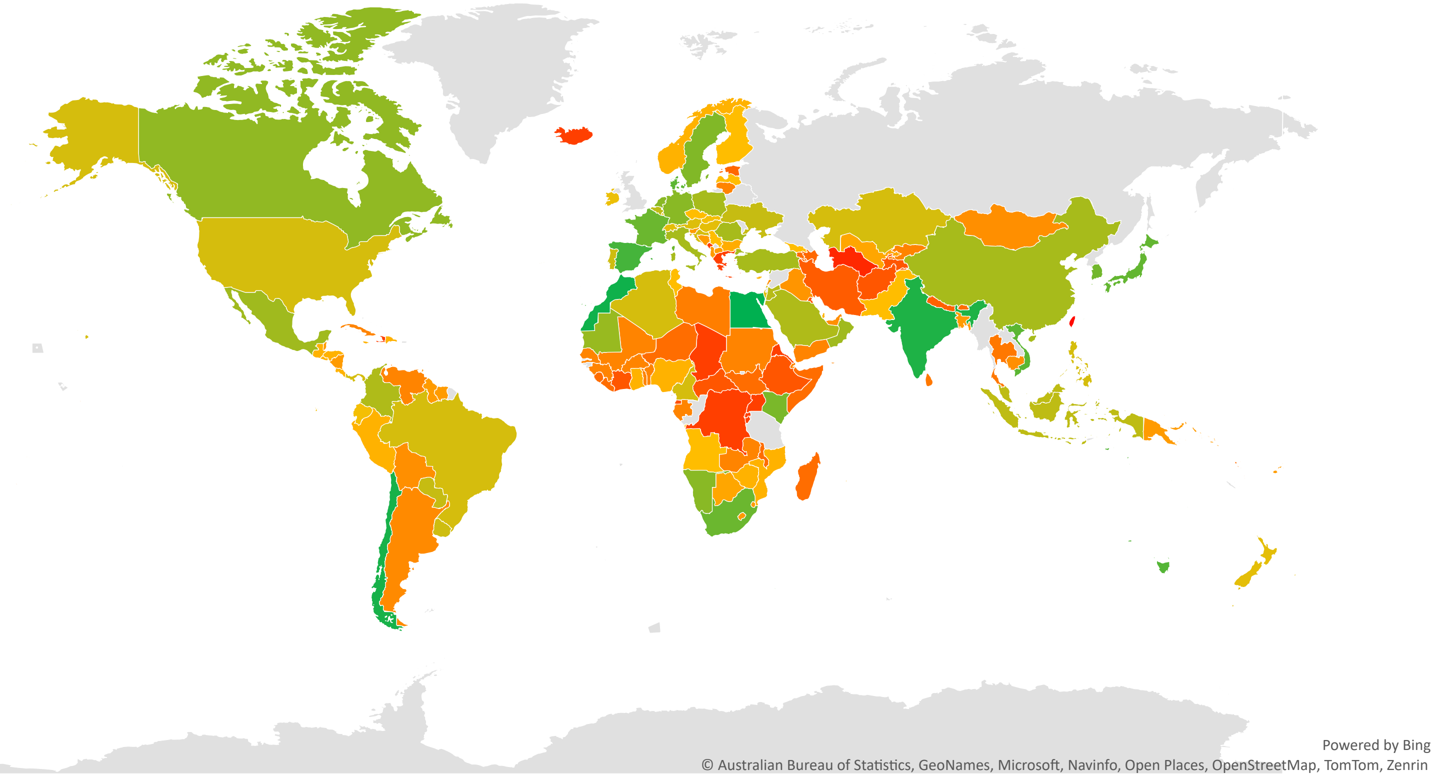
Market Prioritisation
Introduction

Arup conducted a data driven assessment of 170 different markets across the globe to identify five priority markets that offer the most potential for Scotland. The assessment took the form of a multi-criteria analysis, centred around the three core themes presented below, aiming to evaluate markets based on their potential for Scotland to export supply chain capability. This section of the report outlines the assessment framework, analysis & results, priority markets, and sensitivity analysis.

Ambition
What is the size and scale of the market's hydrogen ambitions?

Capability
How capable is the market to be able to deliver on its ambition?

Alignment
How well can Scotland capitalise on the opportunity?



Section 3.1.

Assessment Framework

3.1. Assessment Framework
Introduction

This section of the report presents the assessment framework that was used to analyse markets and identify the priority markets that offer the greatest potential.

As mentioned previously, the assessment framework is grouped by three primary themes: ambition, capability, and alignment. Each of these themes is assessed and scored using three criterion. This section will detail the scoring bounds for each criteria and section 3.2. will detail the analysis and results.

Theme descriptions

Ambition aims to evaluate the scale and size of a given market's hydrogen ambition. A market forecast production and demand were combined with national strategy and funding to create a comprehensive picture of ambition. A greater ambition indicates a more attractive opportunity.

Capability aims to evaluate a market's ability to deliver on its hydrogen ambition. A market perceived to have greater capability represents less potential; lower capability indicates a greater likelihood of a market gap. Hence, markets that are perceived to have the lowest capability are deemed to be the most attractive opportunities.

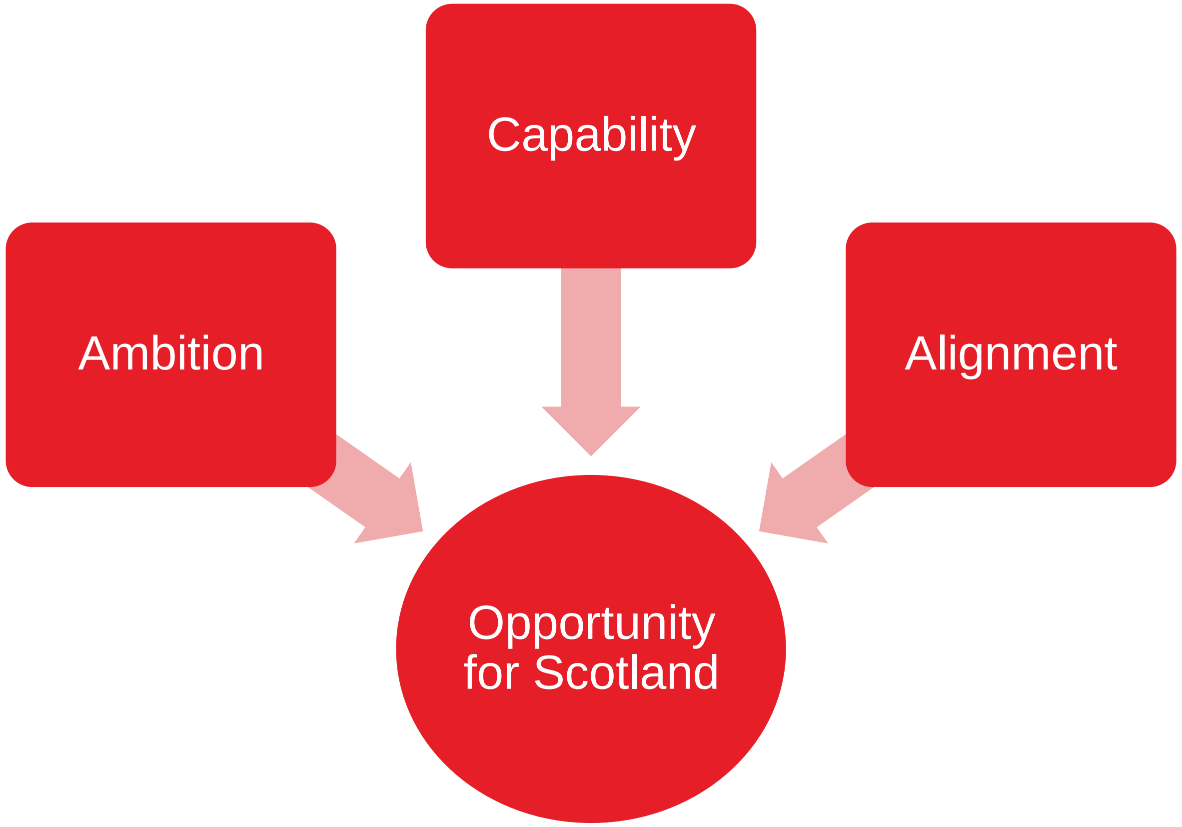
Alignment aims to evaluate how well a market's capability gaps tie with Scotland's export abilities. While the previous two groupings focused on the size and likelihood of an opportunity, this aims to assess how able to Scotland is to capitalise on it. Hence, a greater alignment indicates a more attractive opportunity.

Weighting

The assessment uses a weighted scoring method. A market's scores are weighted by the perceived importance of each criterion.

The weight attached to each criteria was decided in collaboration with the project steering committee to ensure that they reflected the priorities for Scotland. These are presented in the tables within this section.

Ambition, capability, and alignment are weighted equally.



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3.1. Assessment Framework - Ambition

What is the size and scale of the market's hydrogen ambition?

Criteria	Weighting	Scoring				
		1.0	**2.0**	**3.0**	**4.0**	**5.0**
1a. Production		***Limited ambition***		***Median ambition***		***Significant ambition***
How much low-carbon hydrogen will the market produce?	0.40	Less than 10 ktpa of low-carbon hydrogen production	More than 10 ktpa of low-carbon hydrogen production	More than 100 ktpa of low-carbon hydrogen ambition	More than 500 ktpa of low-carbon hydrogen ambition	More than 1,000 ktpa of low-carbon hydrogen production
1b. Demand						
How much hydrogen will the market use?	0.40	Less than 100 ktpa of hydrogen demand	More than 100 ktpa of hydrogen demand	More than 500 ktpa of hydrogen demand	More than 1,000 ktpa of hydrogen demand	More than 5,000 ktpa of hydrogen demand
1c. Hydrogen strategies: targets and funding						
Does the market have a hydrogen strategy in place, and does that strategy specify a target that is backed up by funding?	0.20	No activity	Strategy in preparation	Strategy in place – no target set	Strategy in place – target set, no funding	Strategy in place – target set with funding

3.1. Assessment Framework - Capability

How capable is the market to deliver on its ambition?

Criteria	Weighting	Scoring				
		1.0	**2.0**	**3.0**	**4.0**	**5.0**
2a. Hydrogen		***Significant capability***		***Median capability***		***Limited capability***
How much experience does the market have directly in the hydrogen sector?	0.30	Direct hydrogen experience with deployment greater than 100 MW	Some hydrogen experience with deployment greater than 50 MW	Emerging hydrogen experience with deployment less than 50 MW	A hydrogen trade association but no deployment	No activity
2b. Hydrogen adjacent						
How much experience does the market have in hydrogen adjacent sectors, such as oil and gas, refining, chemicals and biofuels?	0.50	HACI greater than 100	HACI greater than 50	HACI greater than 25	HACI greater than 15	HACI less than 15
2c. Wider						
How developed is the wider economy of the market?	0.20	PCI greater than 60	PCI greater than 50	PCI greater than 40	PCI greater than 30	PCI less than 30

HACI – Hydrogen Adjacent Capability Index; normalised measure of hydrogen adjacent capability; assessed by Arup.
PCI – Productive Capacities Index; measure of overall productive capacity development; source: UN Conference on Trade and Development.

3.1. Assessment Framework - Alignment

How well can Scotland capitalise on the opportunity?

Criteria	Weighting	Scoring				
		1.0	**2.0**	**3.0**	**4.0**	**5.0**
3a. Market		***Limited alignment***		***Median alignment***		***Significant alignment***
How well does the hydrogen activity within the market align with the capabilities of Scotland?	0.40	-	MAI less than 95	MAI greater than 95	MAI greater than 115	-
3b. Political and trade						
How easily will Scotland be able to export capability to the market, with regards to political relationship?	0.40	Sanctions in place	No existing trade	Existing trade	Trade agreement in negotiation	Trade agreement in place
3c. Thought leadership						
Does the opportunity stand out to Arup or Scottish Enterprise?	0.20	Limited opportunity	-	Default	-	Significant opportunity

MAI – Market Alignment Index; measure of the alignment between market activity and Scotland's capabilities; assessed by Arup.

Section 3.2.

Analysis and Results

3.2. Analysis and Results
Ambition

Production forecast

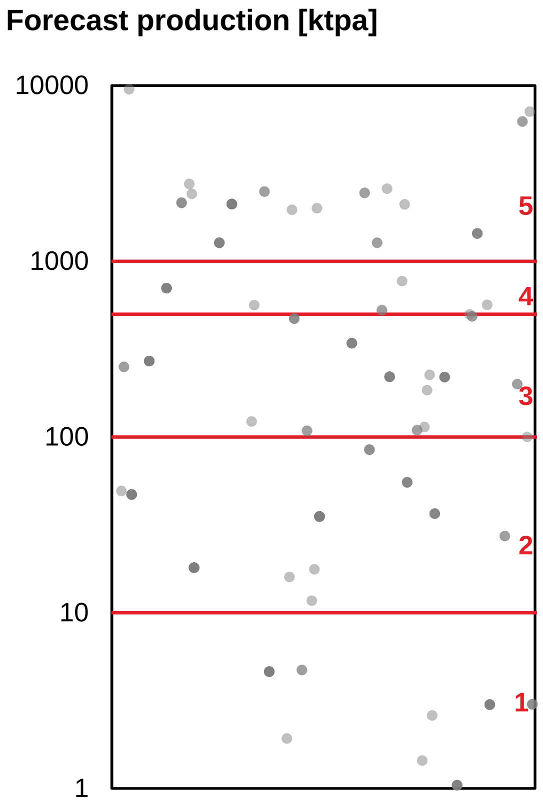
A market's forecast low-carbon hydrogen production was the first metric used to assess the size and scale of its hydrogen ambition. A greater volume of hydrogen production indicates that a country will have a greater number of production projects and require more developed hydrogen infrastructure for distribution and storage. This would require an overall more developed supply chain and, consequently, indicates a greater potential opportunity for Scottish companies.

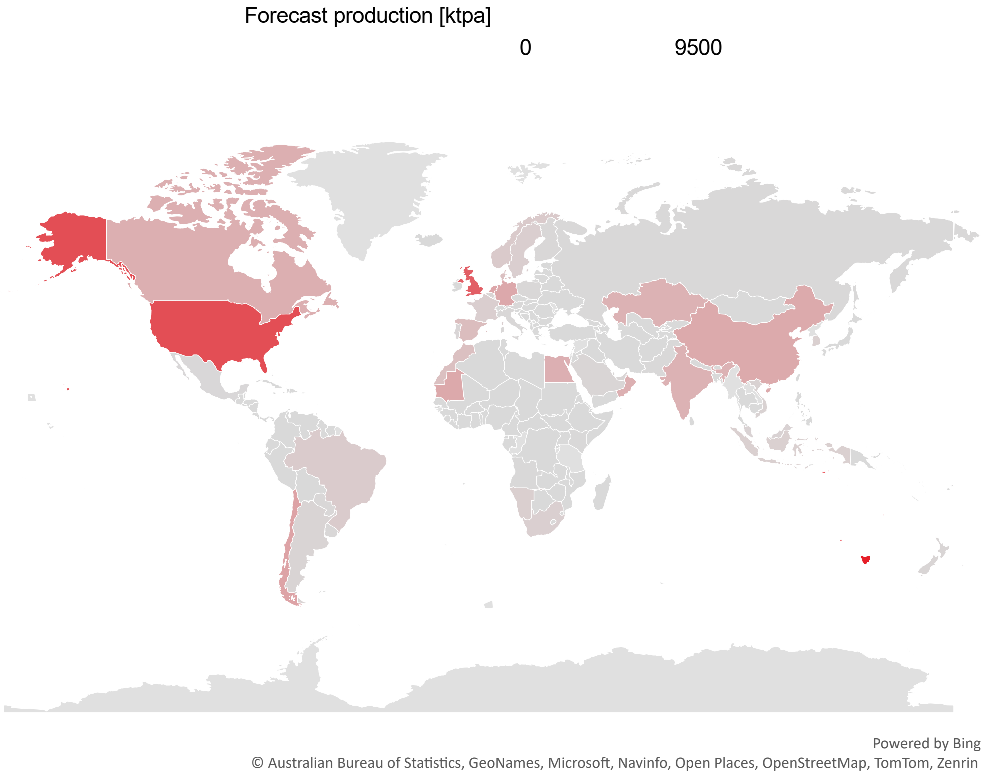
Production was forecast via an assessment based on data sourced from BloombergNEF. The data contained project-level information, such as production capacities, technology, and commissioning year. This was compiled to deliver an understanding of low carbon hydrogen production out to 2040.

Scoring bounds were set on a quasi-logarithmic scale to reflect the substantial differences in magnitude of production. Each scoring bound aimed to group a similar number of markets.

The results of the assessment are presented opposite. On the left, the spread of forecast production is illustrated in relation to the bounds set out in the assessment framework. On the right, forecast production is mapped showing variation.

The results show that a relatively small number of markets are forecast to have a significant volume of low-carbon hydrogen production, while the majority will likely have limited production.





Production Forecast – spread of data in relation to scoring bounds (left) and heatmap (right).

Source: Arup assessment based on data from BloombergNEF.

3.2. Analysis and Results
Ambition

Demand forecast

A market's forecast demand for hydrogen was the second metric used to assess the size and scale of the market's hydrogen ambition. Similar to forecast production, a greater demand indicates a greater potential opportunity for Scotland, particularly in the use segment of the supply chain.

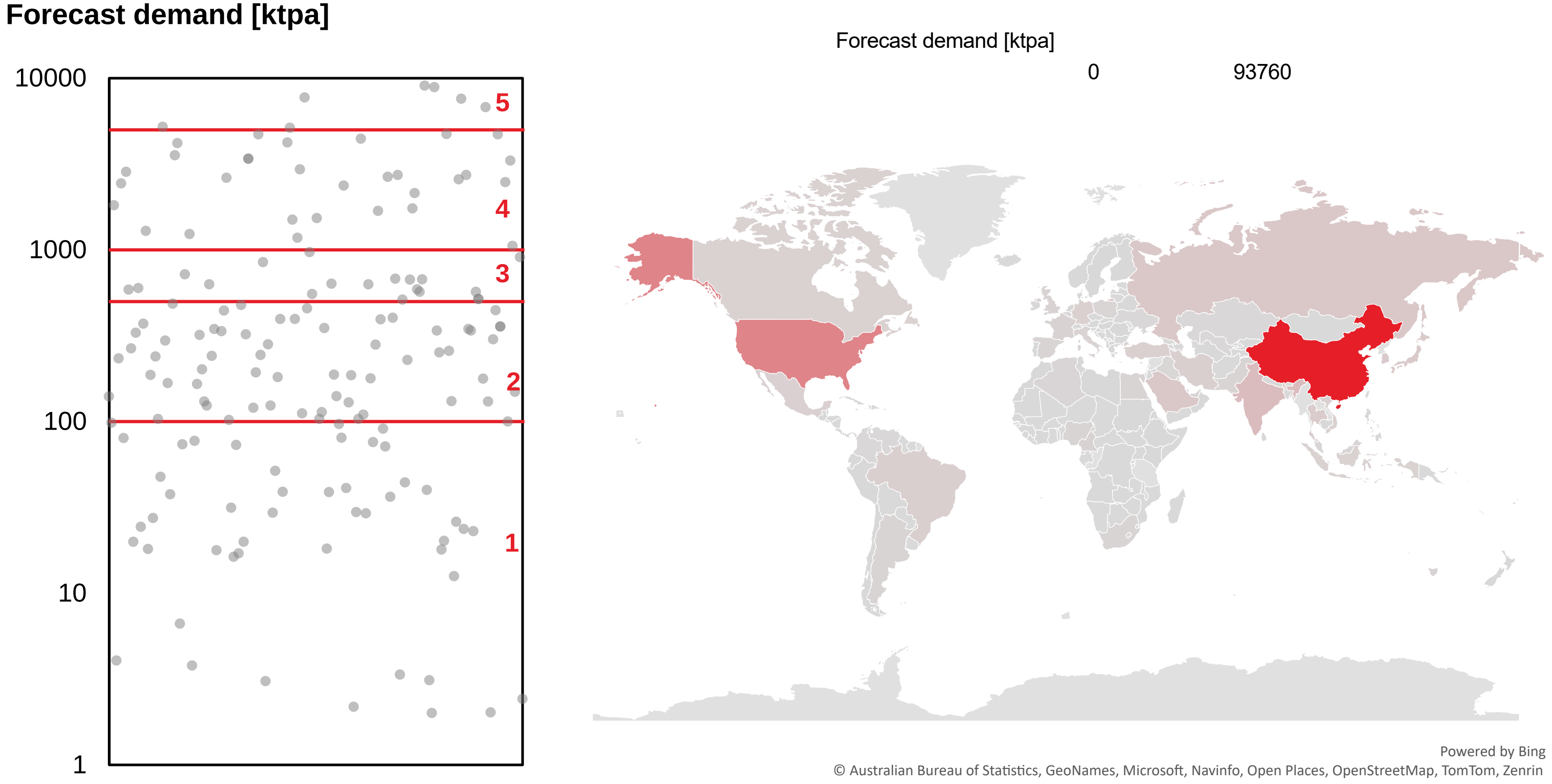
Demand was forecast by market at the sector level in an assessment using the below formula. This was based on data from Our World in Data, the International Energy Agency, BloombergNEF, and the Royal Society of Chemistry.

It was assumed that there was a relationship between a market's greenhouse gas emissions and future demand for hydrogen; i.e., large carbon emitters are more likely to have a greater demand for hydrogen. This assessment considered hydrogen use in industry, transport, power, and buildings. Further details are presented in Appendix A.

Scoring bounds were set on a quasi-logarithmic scale to reflect the substantial differences in magnitude of demand. Each scoring bound aimed to group a similar number of markets.

The results of the assessment are presented opposite. On the left, the spread of forecast demand is illustrated in relation to the bounds set out in the assessment framework. On the right, forecast demand is mapped showing variation.

Similar to production, this suggests that a relatively small proportion of countries will have the greatest demand for hydrogen, while the remaining markets are clustered the middle.



Demand Forecast – spread of data in relation to scoring bounds (left) and heat map (right)

Source: Arup Assessment based on data from Our World in Data, International Energy Agency, BloombergNEF, and the Royal Society of Chemistry.

ARUP

3.2. Analysis and Results
Ambition

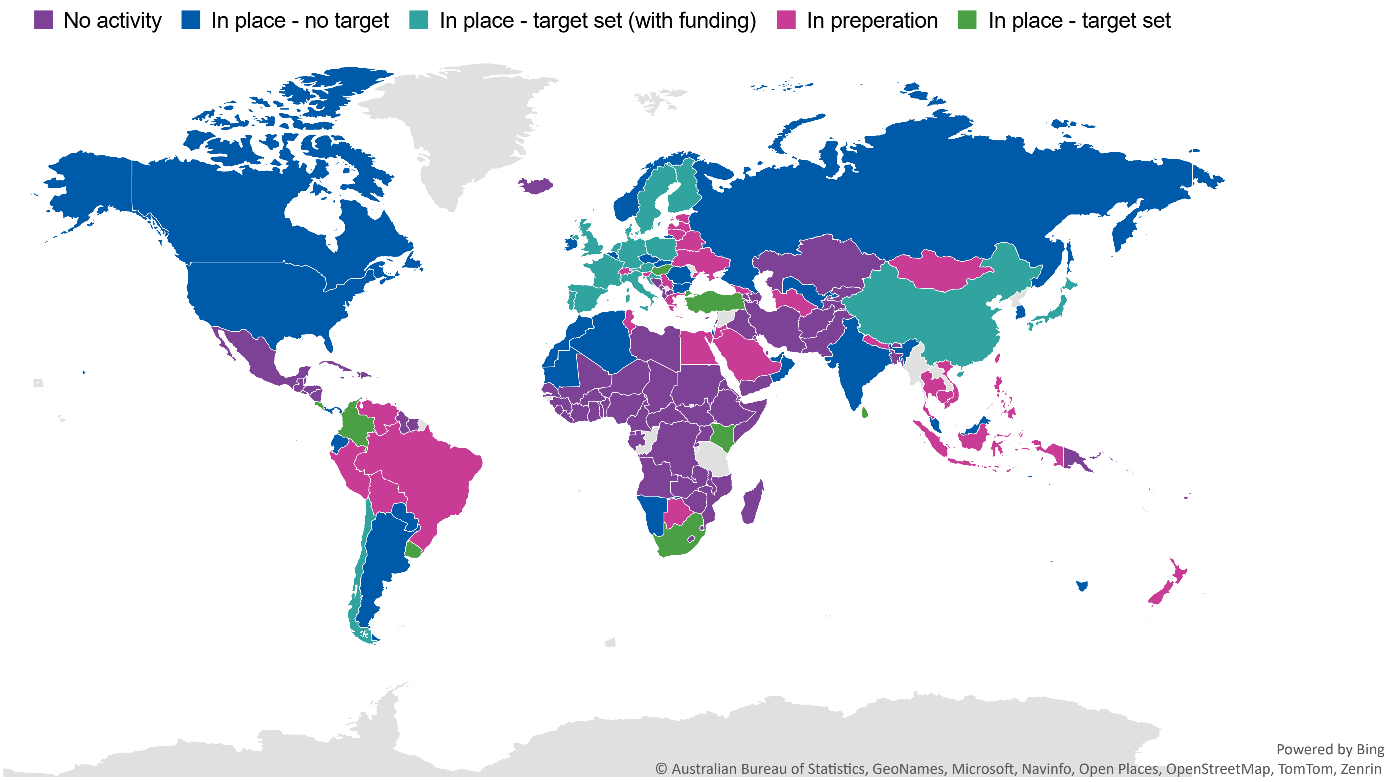
Hydrogen strategies: targets and funding

A market's hydrogen policy environment was the third metric used to assess its hydrogen ambition. A supportive policy environment suggests that the forecast levels of production and demand are more likely to be realised, along with indicating that the government's plan for hydrogen to play a prominent role in its future economy. As a result, a more supportive environment indicates a greater potential for Scottish export.

The policy environment was assessed based on the status of the market's hydrogen strategy. A government that has published a strategy in place, with clear targets that are backed up by some level of public funding was deemed to be the most attractive. In contrast, a government with no strategy activity was deemed to be the least attractive. The assessment was conducted based on data from BloombergNEF and a review of literature to fill any gaps.

The results of this assessment are mapped opposite based on the categories defined in the assessment framework, showing the variation in hydrogen strategy status.

This shows that most governments have made some form of progress towards developing a hydrogen strategy, with a significant number having published one. However, fewer countries have set a specific production target that is backed up by funding.



Hydrogen Strategies

Source: Arup assessment based on data from BloombergNEF.

3.2. Analysis and Results
Capability

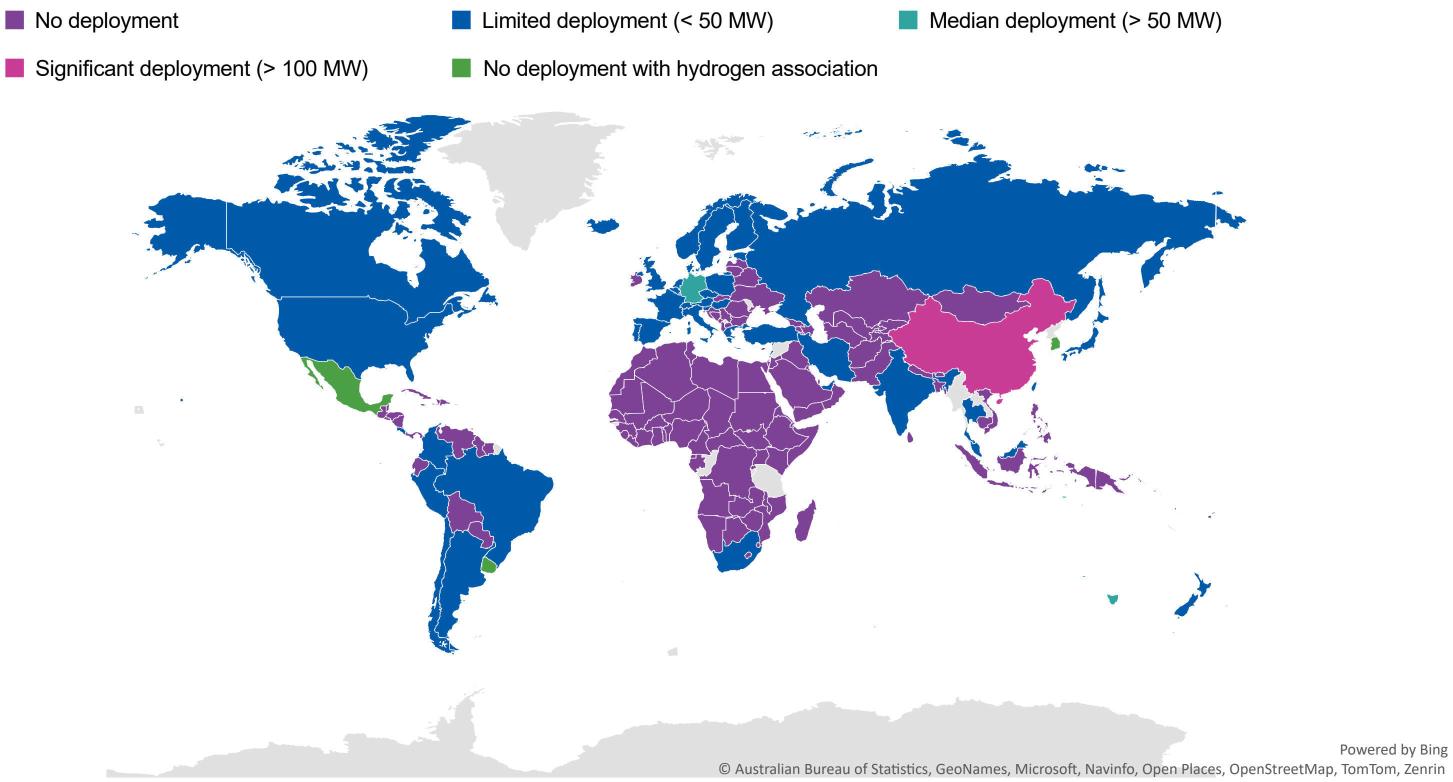
Hydrogen capability

A market's hydrogen capability was the first metric used to assess its capability to deliver on hydrogen ambition. Hydrogen capability is resource and capacity within the supply chain that has direct experience within the low carbon hydrogen sector. A market with a lower hydrogen capability is more likely to have a gap in the supply chain and, consequently, represents a more desirable option for Scotland.

The hydrogen capability assessed was primarily based on the historic deployment of low carbon hydrogen projects. This was based on data sourced from the International Energy Agency. A market with a greater level of deployment was deemed to have a greater hydrogen capability and, hence, is a less desirable opportunity. Those that have not previously deployed any low carbon hydrogen projects were differentiated based on the presence of a national hydrogen association, as the presence of an association indicates a higher level of readiness and capability. Overall, a market that has no deployment is the most likely to have a gap within the supply chain which Scotland can capitalise on.

The results of the assessment are mapped opposite based on the categories defined in the assessment framework. This shows the variation in hydrogen capability.

This illustrates that most countries have limited hydrogen capability, with either no deployment or only at small scale, which is reminiscent of a nascent sector. Only three markets have a median or significant level of deployment.



Low-Carbon Hydrogen Deployment

Source: Arup assessment based on data from the International Energy Agency and H2 Bulletin.

ARUP

3.2. Analysis and Results
Capability

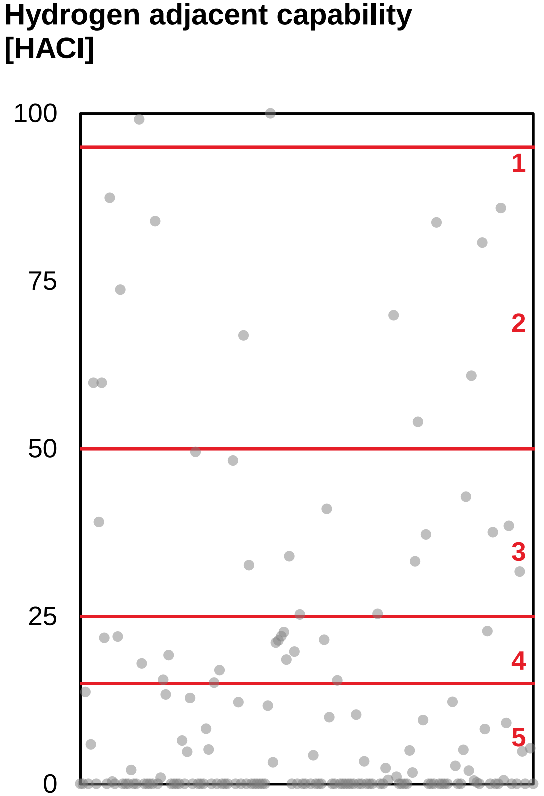
Hydrogen adjacent capability

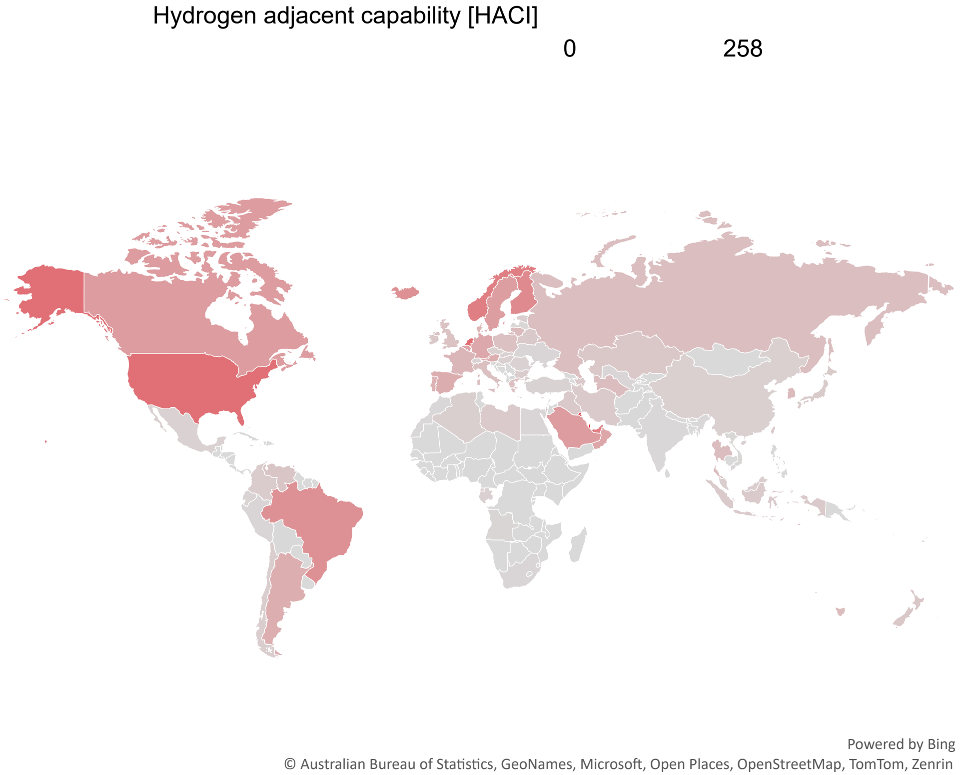
A market's hydrogen adjacent capability was the second metric that was used to assess its capability to deliver on its hydrogen ambition. Hydrogen adjacent capability is resource and capacity within the supply chain that does not have direct hydrogen experience but operates in a similar sector and would be easily able to transition. Similar to direct capability, a lower adjacent capability indicates a greater likelihood of a supply chain gap and represents a more attractive opportunity for Scotland.

Hydrogen adjacent capability was evaluated using the Hydrogen Adjacent Capability Index (HACI), which was created for the purpose of this analysis. The HACI is a normalised, per capita measure of the energy output of hydrogen adjacent industries in a given market; a higher HACI indicates a higher capability and a less attractive opportunity. The adjacent industries considered in this assessment were oil and gas production, refinery capacity, and biofuel production. Data for the assessment was sourced from the Energy Institute's Statistical Review of World Energy for 2023. For each country, per capita energy output for adjacent sectors was summed and normalised.

The results of the assessment are presented opposite. On the left, the spread of HACI is illustrated in relation to the bounds set out in the assessment framework. On the right, HACI is mapped showing variation.

This shows that the majority of countries have limited hydrogen adjacent capability, which is reflective of the concentration of adjacent sectors in relatively few markets.





Hydrogen Adjacent Capability Index – spread of data in relation to scoring bounds (left) and heatmap (right).

Source: Arup assessment based on data from the Energy Institute's Statistical Review of World Energy for 2023.

3.2. Analysis and Results
Capability

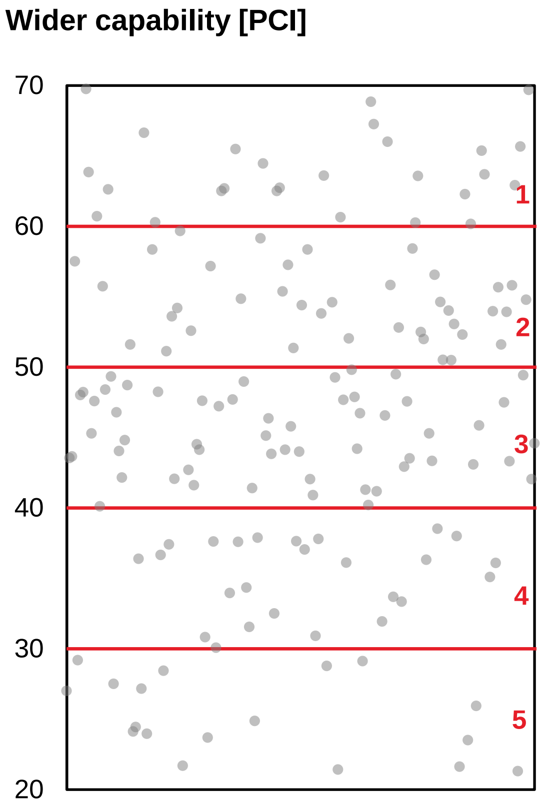
Wider capability

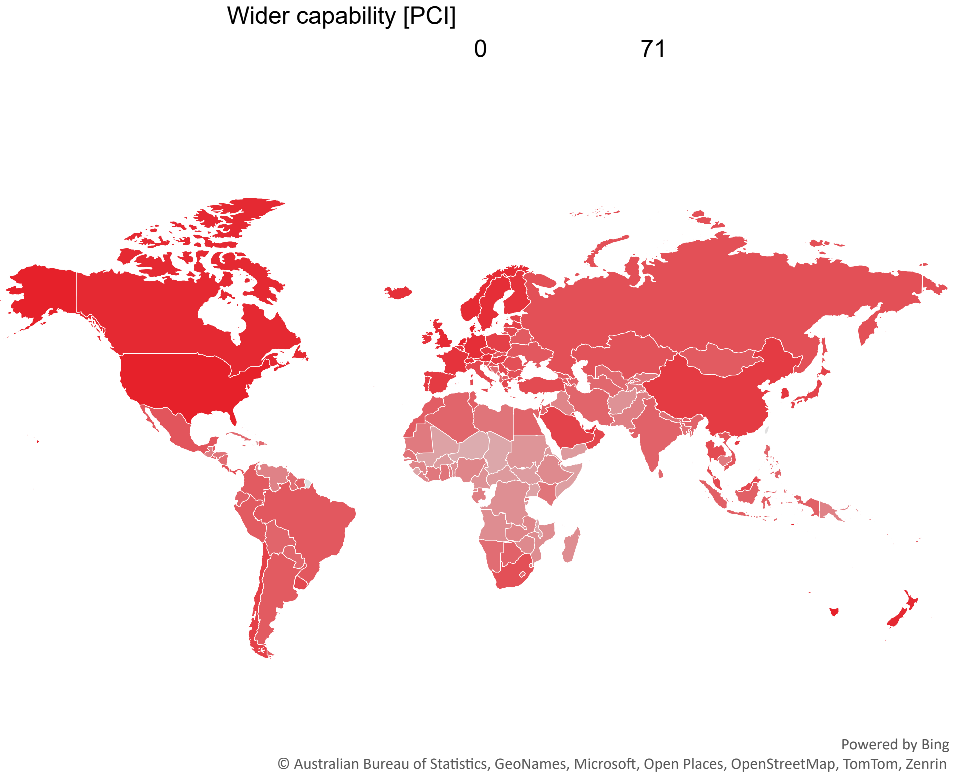
A market's wider capability was the third metric used to assess the its capability to deliver on its hydrogen ambition. Wider capability is the overall resource and capacity within the supply chain and, while it does not necessarily relate to hydrogen, it will contribute to a country's overall capability. As with the previous two capability metrics, a lower wider capability indicates a greater likelihood of supply chain gaps that Scotland can capitalise on.

The wider capability of a market was evaluated using the Productive Capacities Index (PCI). The index is defined and analysed by the United Nations Conference on Trade and Development. PCI is a comprehensive measure of the productive capacities in a country and assesses a market's ability to produce goods and services[1]. This includes human capital, natural capital, energy, transport, information and communication technology, institutions, private sector, and structural changes. PCI was used as it is a simple and recognised approach for comparison. A greater PCI indicates greater capability and a less attractive opportunity for Scotland.

The results of the assessment are presented opposite. On the left, the spread of PCI is illustrated in relation to the bounds set out in the assessment framework. On the right, PCI is mapped showing variation.

This shows an equal spread of scores, with a significant number of countries with strong wider capability.





Wider Capability – spread of data in relation to scoring bounds (left) and heatmap (right).

Source: United Nations Conference on Trade and Development

1. Productive Capacities Index | UNCTAD

3.2. Analysis and Results

Alignment

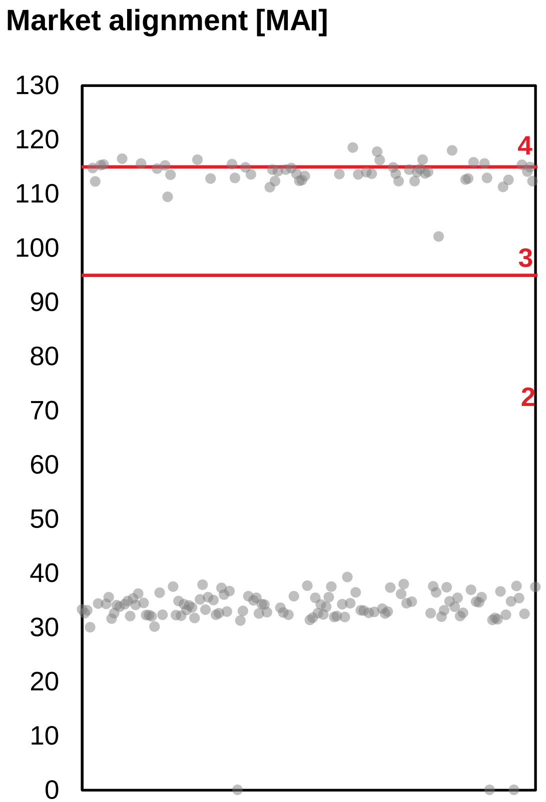
Market alignment

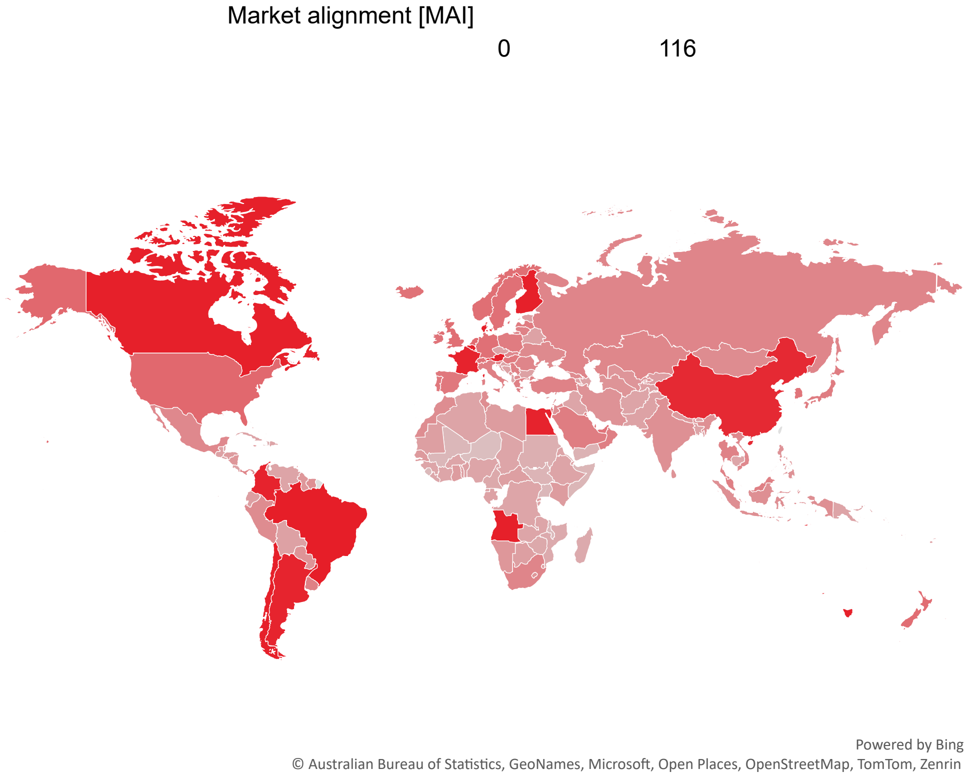
Market alignment was the first metric used to assess how well a country aligns with Scotland's export ability. This is how well a market's hydrogen plans (e.g., production methods and use sectors) align with the capabilities that Scotland possesses. A greater alignment indicates that Scotland would be more capable of capitalising on opportunities.

Market alignment was evaluated using the Market Alignment Index (MAI), which was created for the purpose of this analysis. The MAI is Scotland's capability in a given subsegment of the supply chain weighted by that subsegment's share of the market. (For example: a subsegment would be 'green hydrogen' within the production segment, or 'transport' within the use segment). Scotland's capability within a subsegment is presented in section 2.1. and was evaluated using the qualitative approach discussed in that section. A greater MAI indicates greater alignment and a more attractive opportunity for Scotland.

The results of the assessment are presented opposite. On the left, the spread of MAI is illustrated in relation to the bounds set out in the assessment framework. On the right, MAI is mapped showing variation by market.

This shows two concentrated groupings: (1) those with strong alignment; and (2) those with weak alignment. This assessment aimed to differentiate those markets with strong alignment by setting a scoring boundary within that grouping, however this approach could be refined in a future assessment.





Market Alignment – spread of data in relation to scoring bounds (left) and heatmap (right).

Source: Arup assessment based on data from Scottish Enterprise.

ARUP

3.2. Analysis and Results
Alignment

Political and trade alignment

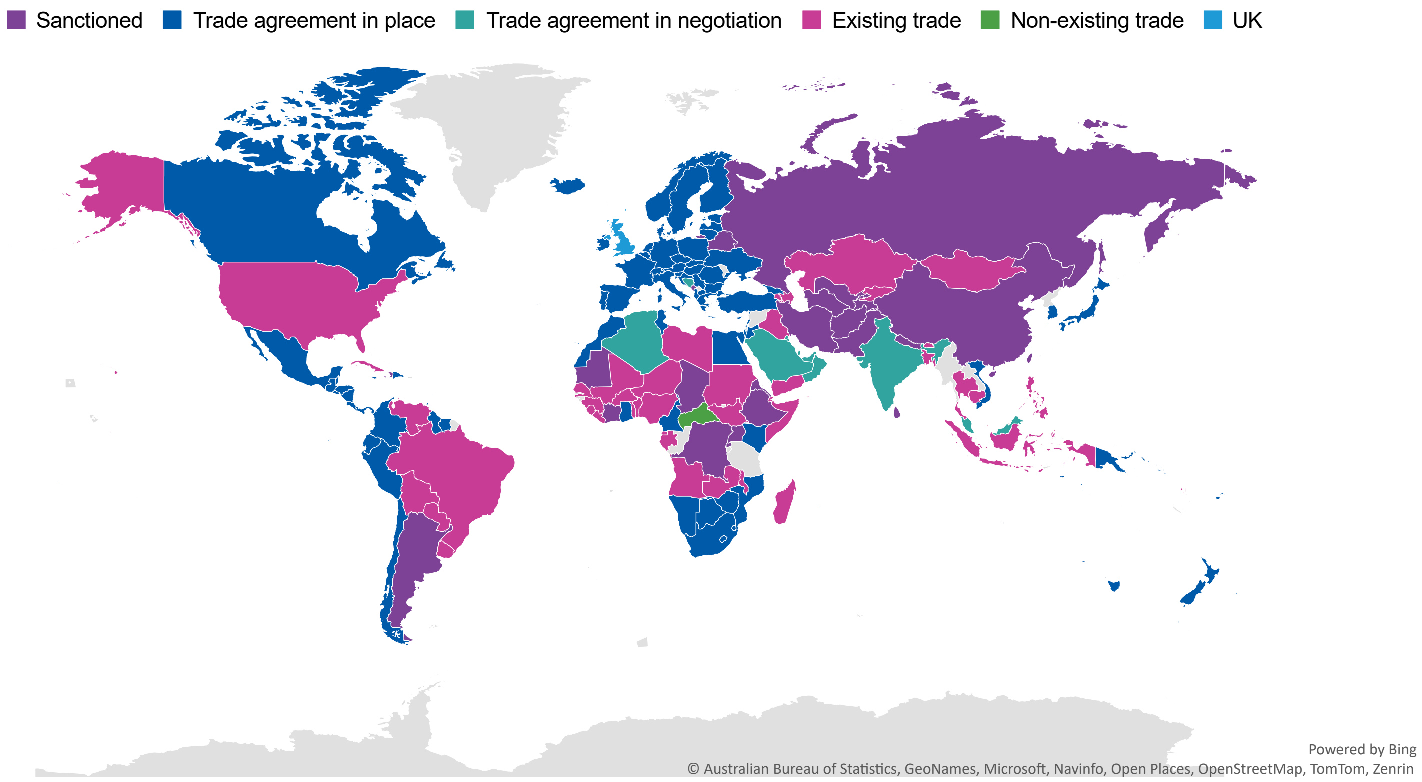
A market's political and trading relationship with the UK was the second metric used to assess how well it aligns with Scotland's export ability. A strong trading and political relationship indicates that exporting products, solutions, and services to the country would be more straightforward. Consequently, this would be a more attractive opportunity for Scotland. Political and trade alignment is the perceived strength of this relationship.

Political and trade relationship is derived from information and data relating to the UK as Scotland primarily conducts international relations through UK government.

The political and trade alignment was evaluated by examining the status of trade between the UK and a given market in an assessment based on data from the UK government and Office for National Statistics. A country with a trade agreement in place was deemed to be the most attractive opportunity due to the perceived ease of trading. Conversely, a market that is currently sanctioned was deemed to be the least attractive opportunity due to the perceived difficulty of trade.

The results of this assessment are presented opposite based on the categories defined in the assessment framework. This shows the variation in political and trade alignment by market.

This indicates that Scotland has good political and trade alignment with many markets, and relatively few representing a significant barrier.



Trade Status with the UK

Source; UK Government and the Office for National Statistics

3.2. Analysis and Results

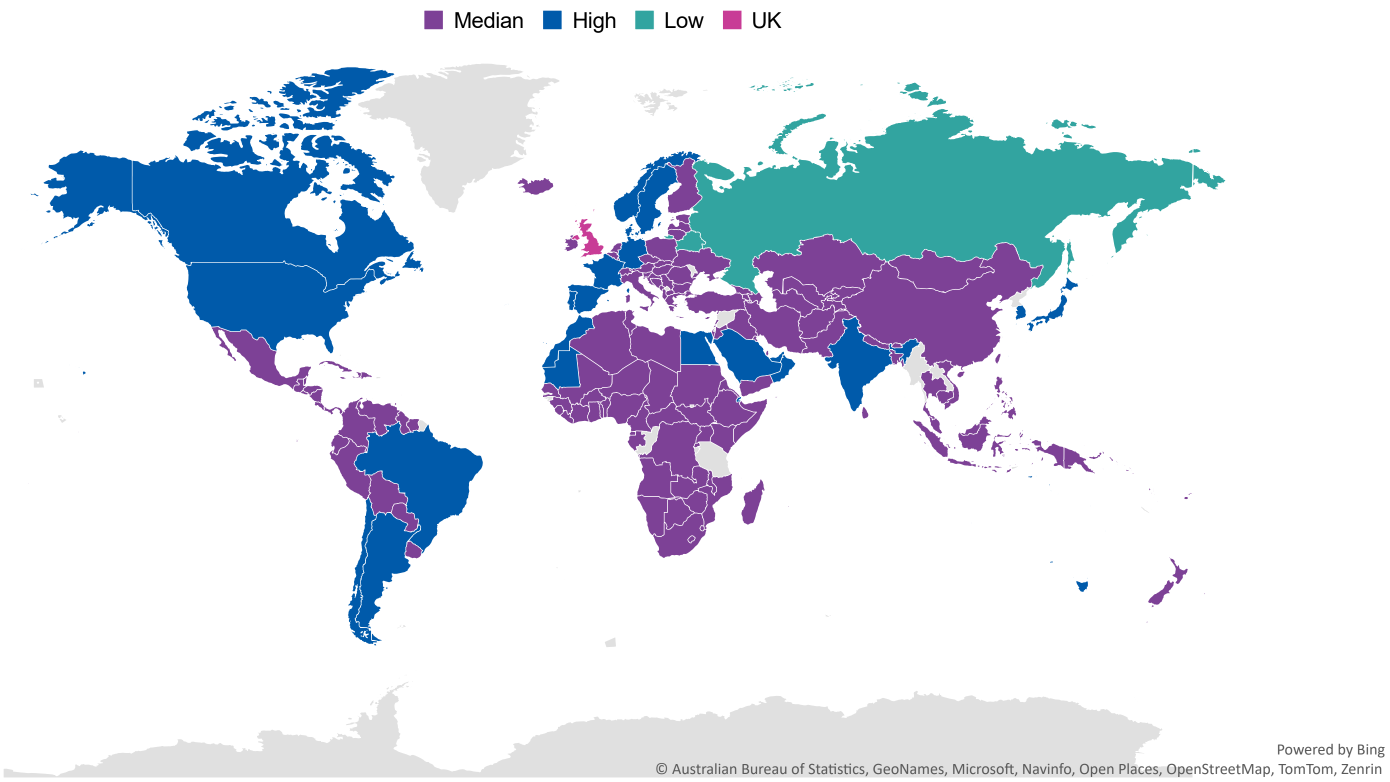
Alignment

Thought leadership

A thought leadership piece was used as the third metric to assess a market's alignment with Scotland's export ability. The piece was a collaborative exercise between Arup and the wider project steering group within Scottish public sector. This piece was used to identify markets where significant progress was being made, or Scottish companies were already making an impact.

As presented in the assessment framework, the scores for this criteria were modulated around the median score of three. The most attractive markets were given a score of five; unattractive markets were given a score of one; and any remaining markets were given a score of three by default.

The results of this assessment are presented opposite based on the categories defined in the assessment framework. This shows the variation by market.



Attractiveness of Markets

Source: Project Steering Group

Section 3.3.

Priority Markets

3.3. Priority Markets

Overview

Following the market prioritisation assessment, five markets were selected based on their scores and the outcomes of a workshop between the public sector steering group and Arup. The five priority markets selected are:

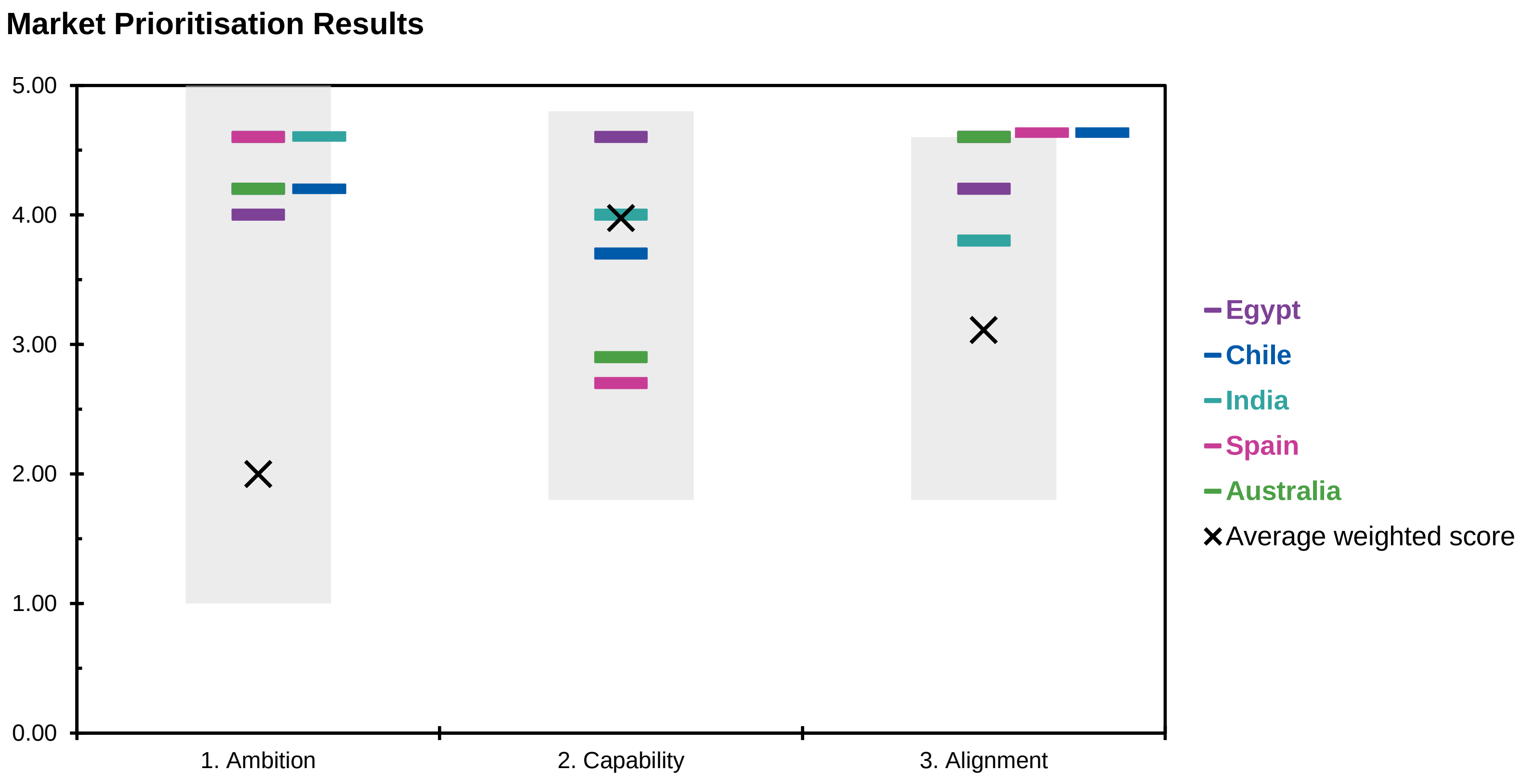
- Egypt
- Chile
- India
- Spain
- Australia

Presented opposite are the scores of these five markets broken-down by criteria grouping. This is in addition to average and range weighted scores for all the markets assessed.

The five markets selected score consistently highly in hydrogen ambition and alignment to the Scottish market, while there is a clear variation in the capability scores.

Morocco was the second highest scoring market. However, Australia (the 6th highest scoring market) was selected as a priority market instead. This decision was driven by Morocco's proximity and close links to Spain and Egypt, and to provide more geographic variety in the markets assessed further. Morocco has been included as an adjacent market within Spain's section of the report.

In the following pages of this section, the reasoning behind the scoring for each priority market is discussed.



Market Prioritisation Results

Source: Arup assessment

3.3. Priority Markets

Egypt

Overview

Egypt scored the highest out of the markets that were assessed, with a weighted score of 12.8 out of 15. This was primarily driven by the likelihood of a supply chain gap. The market is in the early-stages of its hydrogen journey, with an emerging supply chain and growing ambition. It should also be noted that Scottish success in Egypt may lead to further opportunities in adjacent markets in North Africa and the Middle East.

Ambition

The Egyptian market has strong hydrogen ambition, and while it has the weakest ambition of the five priority markets, the size and scale of ambition represent a clear opportunity for Scotland. The market still scored within the top 10% of those assessed, being particularly strong with production and demand, while national policy is still emerging.

Egypt is forecast to have substantial low carbon hydrogen production. As previously discussed, Egypt has a planned production capacity of over 2,000 ktpa by 2040. This is combined with nearly 4,000 ktpa of planned capacity that is yet to confirm a commissioning date. This places Egypt in the top 10 markets for production capacity, resulting in it achieving the highest score for this criteria point.

Additionally, Egypt is likely to have significant in-market demand. This was forecast to be approximately 2,700 ktpa in 2050. While the market demand is comparatively weaker to its production position, it still placed within the top 30 markets. Furthermore, this is reflective of Egypt's overall plans to be an exporter. This resulted in a score of 4 out of 5.

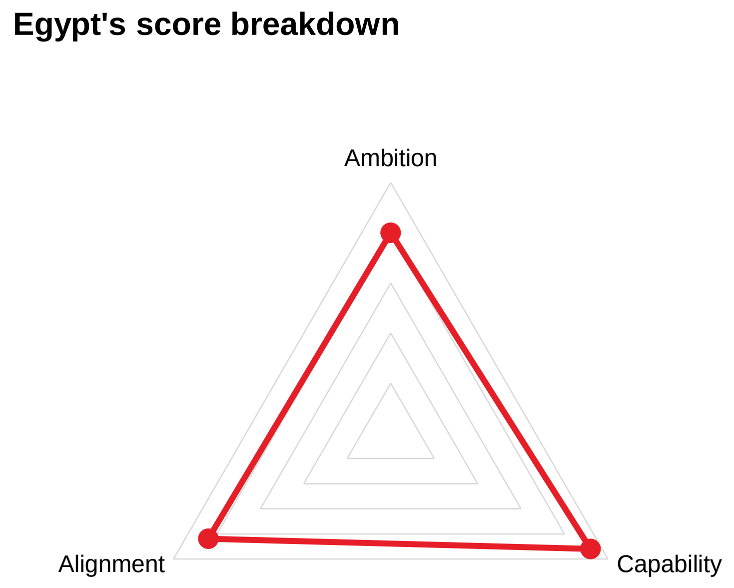
Egypt’s policy ambition is its weakest area – their hydrogen strategy is still in preparation. This resulted in the market scoring a relatively weak score of 2. However, there is clear progress being made with the development of the strategy.

Capability

Egypt had the highest score for capability. There is potentially a large gap within the market’s supply chain for Scotland to capitalise on. Egypt to date has no low carbon hydrogen deployment, indicating a lack of direct experience in the delivery of projects. Moreover, assessment of adjacent capability indicates a further lack of experience in sectors that would easily be able to transitions to support the delivery of hydrogen projects. Overall, this suggests that Egypt will require a high degree of external support to be able to deliver on its hydrogen ambition.

Alignment

Egypt aligns well with the ability for Scotland to export to the market. The UK currently has a trade agreement in place with Egypt, indicating positive relationship and likely ease of doing business. Moreover, Egypt was identified during the thought leadership exercise as a market that offered some of the greatest potential.



Egypt market assessment score

Source: Arup Assessment

ARUP

3.3. Priority Markets
Chile

Overview

Chile was the third highest scoring market in the market prioritisation exercise with a score of 12.5 out of 15. This was primarily driven by its strong hydrogen ambition and alignment with Scotland. This section of the report will present a more detailed market assessment of Chile.

Ambition

The Chilean market scored within the top 10% of those assessed, being particularly strong with planned production targets and national policy backed up with funding.

Chile has strong hydrogen ambition, with a hydrogen strategy in place backed by government funding and a pilot project programme. The pace and scale of ambition in Chile represents opportunity for Scotland to support the pipeline of projects that will be required to meet these ambitions in a relatively new market.

Capability

While Chile has strong ambitions to become a world leader in hydrogen production and export, to date there has been limited deployment of hydrogen on the ground (<50MW). Six pilot projects are underway, backed by the Chilean government, and are expected to be operational by 2025. Hydrogen project development is expected to increase significantly by 2030. Therefore, there will likely be a significant requirement for services and innovation in the short term to develop the projects and equipment, engineering and EPC skills for build-out.

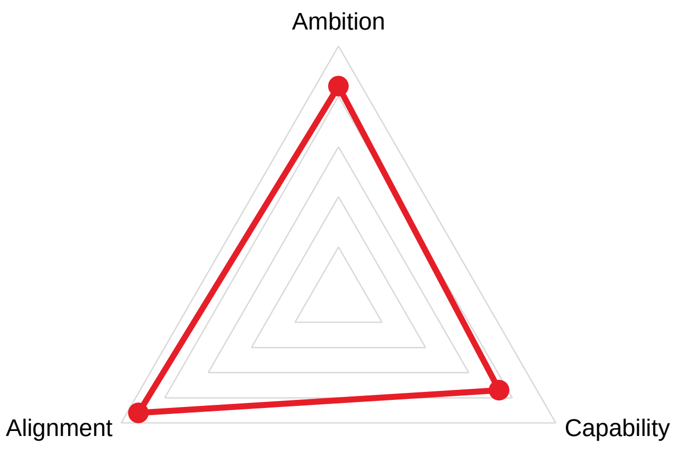
As Chile imports the majority of its energy supply, there could be opportunity for Scotland to provide expertise and technology gained from its domestic renewables, oil and gas sectors. In addition, key planned offtake sectors include transport and blending which Scotland may be able to provide early knowledge and experience around.

Alignment

Chile scored highly across all alignment factors, including the size of market, political and trading alignment. There are currently a trade agreements in place, including the CPTPP and UK-Chile association agreement, and preferential tariff rates on UK exports to Chile are being applied. Overall Chile is a country with good business practices, low corruption and strong democratic institutions.

Energy costs in Chile are currently high and, as mentioned previously, the country relies on a significant proportion of imported fossil fuels. Therefore, there are opportunities for Scotland to supply technology and experience in both renewables and green hydrogen. A high proportion of infrastructure and services are privatised in Chile, leading to increased opportunity for private sector involvement. Chile is open to public-private partnerships and many of the developers currently active in Chile are international companies, including Total, Siemens, Cummins, Linde, Engie, RWE Renewables and Enel Green Power, among others.

Chile's score breakdown



Chile market assessment score

Source: Arup Assessment

3.3. Priority Markets
India

Overview

India was the fourth highest scoring market in the market prioritisation exercise with a score of 12.4 out of 15. This was primarily driven by its strong hydrogen ambition and capability. This section of the report will present a more detailed market assessment of India.

Ambition

India had the highest ambition score of the five priority markets. The Indian market scored within the top 10% of those assessed, being particularly strong with planned production targets and national policy backed up with funding.

The Indian market has a hydrogen strategy in place aiming to achieve 5 Mtpa hydrogen production capacity of by 2030. This is backed by substantial funding to support research, manufacturing and project development. The pace and scale of ambition in India represent a clear opportunity for Scotland to support the development of projects to meet these ambitions, along with growing demand.

Capability

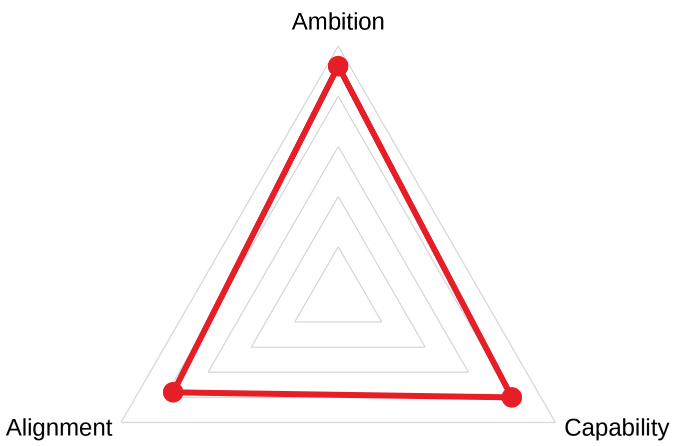
While India has strong ambitions to become a hub for hydrogen production, to date there has been limited deployment of hydrogen on the ground (<50MW). The government is beginning to support development of the supply chain and has launched a bidding round for electrolyser factories in 2023, with contracts expected to be issued within a year. The first hydrogen projects are expected to become operational around 2024. This presents opportunities for hydrogen supply chain capability to be sourced externally, to enable India to accelerate project development at a scale where they can meet their hydrogen ambitions. While most hydrogen projects are being built by Indian developers, there could be opportunities for partnerships and hydrogen application of transport and industry, such as refining, could align well with Scotland's experience and capability.

Alignment

India scored slightly lower in alignment across the priority markets. While there is currently no trade agreements in place with India, negotiations for a free-trade agreement are underway and there is a comprehensive strategic partnership in place as part of the 2030 roadmap for future relations..

The Indian government is promoting the concept of 'self-reliance' to develop Indian businesses, which may make it more difficult for Scottish companies to sell products or services. However, there may be opportunities for Scotland to work in partnership with the Indian hydrogen supply chain.

India's score breakdown



India market assessment score

Source: Arup Assessment

3.3. Priority Markets

Spain

Overview

Spain is a mature market compared to others being assessed. Its score was primarily driven by substantial ambition and strong alignment with Scotland. It was the 5th highest scoring market that was assessed with a weighted score of 11.9 out 15.

Ambition

Spain has clear ambition within the low carbon hydrogen sector, scoring within the top 6 markets for this criteria grouping. This was driven by consistently strong credentials across production, demand, and policy.

Spain will likely have substantial in-market hydrogen production. It is estimated that low carbon hydrogen production will surpass 1,400 ktpa within the next decade, indicating a rapid expansion of the sector and clear opportunity for Scotland. This is combined with a further 3,400 ktpa of capacity with an unspecified completion date.

Similarly, Spain is forecast to have a substantial level of in-market demand. This was forecast to be approximately 2,700 ktpa, placing Spain within the top 25 of markets that were assessed. This is an indication of the downstream activity in the market.

Spain has some of the strongest policy ambition, with a comprehensive hydrogen strategy in place. This sets out a target of 11 GW of electrolyser capacity by 2030, along with over $1.6bn available in funding to support the delivery of low carbon hydrogen projects. This clearly demonstrates the supportive policy environment within the market.

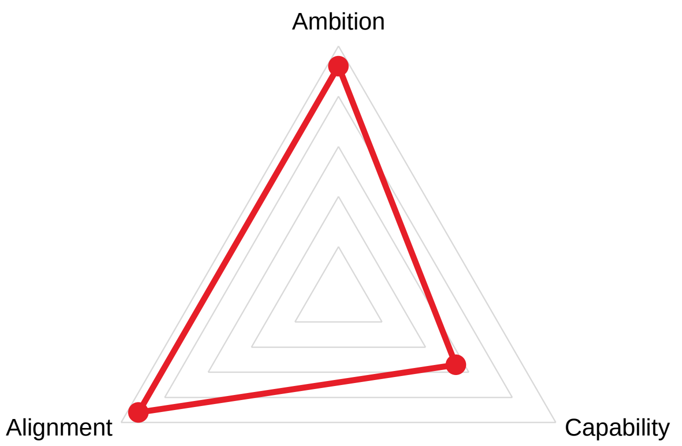
Capability

Spain's capability is the greatest threat to Scotland capitalising on the opportunities within the market. Spain has direct experience within the low carbon hydrogen sector: 23 projects have been delivered with a cumulative capacity of c. 40 MW, the largest of which was a 20 MW electrolyser. Furthermore, Spain has strong hydrogen adjacent capability, primarily driven by significant refinery capacity.

Alignment

Spain aligns well with Scotland's ability to export to the market. There is currently a trade agreement between the UK and Spain, through the UK's agreement with the EU. Additionally, a close and positive political relationship exists between the markets. Moreover, Spain was identified as part of the thought leadership piece as an attractive market and the likely needs of the market align well with Scotland's strengths.

Spain's score breakdown



Spain market assessment score

Source: Arup Assessment

ARUP

3.3. Priority Markets
Australia

Overview

Australia was the sixth out of the five priority markets with a score of 11.7 out of 15. This was primarily driven by its strong alignment with Scotland. This section of the report will present a more detailed market assessment of Australia. While the market was not in the top 5, it was selected to increase the geopolitical variety of those being assessed.

Ambition

Australia has a strong position in the emerging hydrogen market. With one of the largest pipelines of hydrogen projects, it is expected to become the second largest net-exporter of low-emissions hydrogen by 2030 and the largest by 2050[1]. Australia has a hydrogen strategy in place, although no specific production targets. This is backed by government funding programme Hydrogen Headstart, along with Regional Hydrogen Hub funding. Several pilot projects, including gas blending and refuelling stations, are underway which sets a strong baseline for future hydrogen growth in Australia.

Capability

Capability scored slightly lower than other indicators for Australia. This is due to Australia being relatively advanced in hydrogen deployment compared with other countries (although still at early stage), having several projects already underway or having reached financial development. Investment in the supply chain is also underway, with Fortescue Future Industries have invested $3 billion in their Gladstone electrolyser manufacturing plant. However, Australia is open to international investment, which provides opportunity for Scotland, with many companies already involved in the Australian hydrogen sector, including Aberdeen-based company Xodus Group through their MercurHy project.

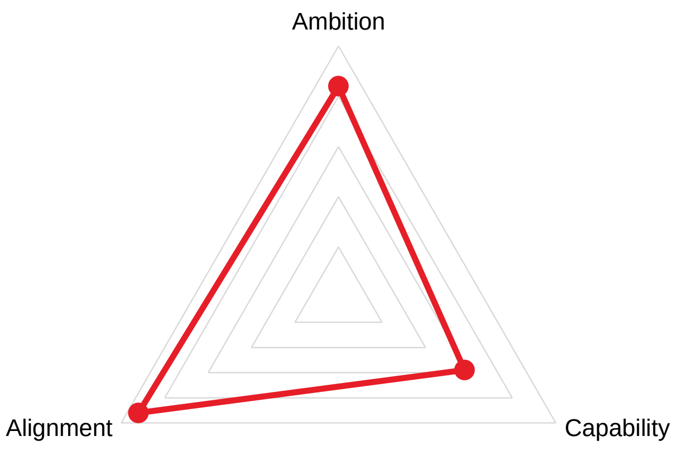
Additionally, as Australia still has a fossil fuel-based energy system, there could be opportunity for Scotland to provide expertise and technology gained from their ongoing energy transition.

Alignment

Australia scored highly across all alignment factors, including the size of market, political and trading alignment. Australia is a stable and resilient economy, open to international investment and collaboration.

There is currently a UK-Australia Free Trade Agreement in place. In addition, Australia and the UK are working together to realise the shared ambition of reaching net zero emissions by 2050 through the Australia–UK Clean Technology Partnership. This involves working with industry to explore options to achieve industrial decarbonisation.

Australia's score breakdown



Australia market assessment score

Source: Arup Assessment

1. Hydrogen: The Clean Fuel of the Future | Global Australia

Section 3.4.

Sensitivity Analysis

ARUP

3.4. Sensitivity Analysis
Introduction

Overview & scenarios

Following the market prioritisation assessment, a sensitivity analysis was conducted. The purpose of this was to investigate how a variation in Scottish priorities would impact the results of the assessment. This was achieved by varying the weight assigned to each group of criteria (ambition, capability, and alignment). Varying the weight of each individual criterion was out of the scope of this analysis. The total sum of weights was kept consistent to allow for easier comparison across scenarios.

Four additional scenarios were considered in addition to the baseline (default) weights. The variation in weightings is presented opposite and each is explained below.

A. Baseline: default weights used in original assessment.
B. Ambition scenario: the assessment prioritises markets with largest hydrogen ambition (i.e., greatest in-market demand and production, with supportive policy).
C. Capability scenario : prioritises markets likely to have the greatest gap within the market.
D. Alignment scenario : prioritises markets that Scotland is most likely able to capitalise on.
E. Opportunity scenario : prioritise markets based on their size and the likelihood of a gap, regardless of Scotland's ability to capitalise on the opportunity.

	Weighting		
Scenario	Ambition	Capability	Alignment
A. Baseline	1	1	1
B. Ambition scenario	3	0	0
C. Capability scenario	0	3	0
D. Alignment scenario	0	0	3
E. Opportunity scenario	1.5	1.5	0

3.4. Sensitivity Analysis
Top scoring markets by scenario

Results

The top scoring markets for each of the scenarios outlined previously are presented opposite.

Ambition scenario

These are the markets that have the greatest level of hydrogen ambition. However, this does not capture the likelihood that there would be a gap within the market, or whether there is any alignment with Scotland.

Capability scenario

These are the markets that would be least likely to be able to deliver on their hydrogen ambition and, as such, are most likely to have a gap within the market. However, this does not account for the overall size of the market. So, while there may be a significant gap in the market, the size of the opportunity may be limited.

Alignment scenario

These markets that align most with Scotland. Scotland's capabilities likely align well with the in-market activity and there is likely a close trade alignment. However, this does not necessarily indicate that there would be a significant opportunity.

Opportunity scenario

These are the markets that represent the greatest potential opportunity, based on external factors. However, this does not account for Scotland's ability to capitalise on the opportunity; the market activity may not align, and it may be politically difficult to enter.

A. Baseline		B. Ambition scenario		C. Capability scenario		D. Alignment scenario		E. Opportunity scenario	
Egypt	12.80	China	15.00	Mauritania	14.40	Chile	13.80	India	12.90
Morocco	12.60	India	13.80	Egypt	13.80	Denmark	13.80	Egypt	12.90
Chile	12.50	US	13.80	Morocco	13.80	Australia	13.80	Morocco	12.60
India	12.40	Spain	13.80	Vietnam	13.80	Spain	13.80	China	12.60
Spain	11.90	Germany	13.80	Kenya	13.80	Sweden	13.80	Chile	12.85
Australia	11.70	Netherlands	13.80	Others*	13.80	Singapore	13.80		

*Philippines, Pakistan, Romania, Uzbekistan, Paraguay, Namibia, Jordan, and Angola.

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Section 4

Priority Market Assessment

Section 4.1.

Egypt

ARUP

4.1. Egypt
Priority Market Assessment

Hydrogen outlook

Egypt has ambitions plans to become a global leader within the low carbon hydrogen sector. The government is currently preparing a $40bn national hydrogen strategy that will target 1.4 GW of hydrogen production by 2030[1]. This is combined with aspirations of capturing 5-8% of the global market, along with generating 100,000 jobs in the sector by 2040[2]. This follows commitments made by Egypt during COP27 and aligns with their wider green energy strategy, Egypt Vision 2030[7]. However, the strategy, which was originally scheduled to be published in 2022, has been delayed, introducing uncertainty and preventing a more detailed assessment. As of November 2023, the strategy has been approved by the National Green Hydrogen Council but remains unpublished[2].

Egypt targets $175bn in investments into the sector by 2030 to deliver 32 projects[3]. Moreover, an $80mn loan was provided by the European Bank for Reconstruction and Development (EBRD) to support the delivery of their first project[4]. At this stage, the exact funding mechanism is unclear; a combination of private and public would be expected, with the potential of $40bn in public funding. A further review of funding arrangements would be beneficial once the strategy is fully published.

Egypt has signed eight framework agreements with prominent companies to facilitate the development of low carbon hydrogen projects[5]. This includes AMEA Power, Alfaner, Total Energies, and Fortescue Future Industries[5]. These companies will likely play a central role in the delivery of low carbon hydrogen projects; any pre-existing relationships or early engagement could facilitate Scottish companies' involvement in the market.

Egypt currently produces and consumes large volumes of grey hydrogen. An estimated 1,825 kt were consumed and produced in the market in 2019[6]. It was primarily used in ammonia production, steel production, and refining, representing 41%, 35%, and 16% of demand respectively[6]. Egypt's strategy will likely focus on displacing this with low carbon hydrogen, followed by export[7], both of which potentially limit the opportunities for Scottish involvement due to existing capability. However, there are likely to be several emerging uses, namely in the power and transport sectors, where Egypt will have lower capability. Hydrogen could be used to provide flexibility services to an increasing solar and wind grid. Moreover, compressed natural gas vehicles are widely used, with plans to increase their use, including in buses, announced in 2020[8]. Low carbon hydrogen provides a sustainable alternative to compressed natural gas.

1.4GW

planned 2030 target

$40bn

planned strategy

1. Egypt is looking to adopt hydrogen technology to further diversify its energy mix - Africa 2022 - Oxford Business Group
2. National Green Hydrogen Strategy gets National Green Hydrogen Council's approval – EgyptToday
3. Egypt targets $175bn investments in green H2 by 2030 | Argus Media
4. EBRD supports first green hydrogen facility in Egypt
5. COP27 - Egypt Signs Eight Framework Agreements for Hydrogen Projects, Including an $8 Billion Green Hydrogen Factory - Hydrogen Central (hydrogen-central.com)
6. Egypts-Low-Carbon-Hydrogen-Development-Prospects-ET04.pdf (oxfordenergy.org)
7. Egypt | UNIDO Green Hydrogen
8. CNG: Driving on The Route to Success | Egypt Oil & Gas (egyptoil-gas.com)

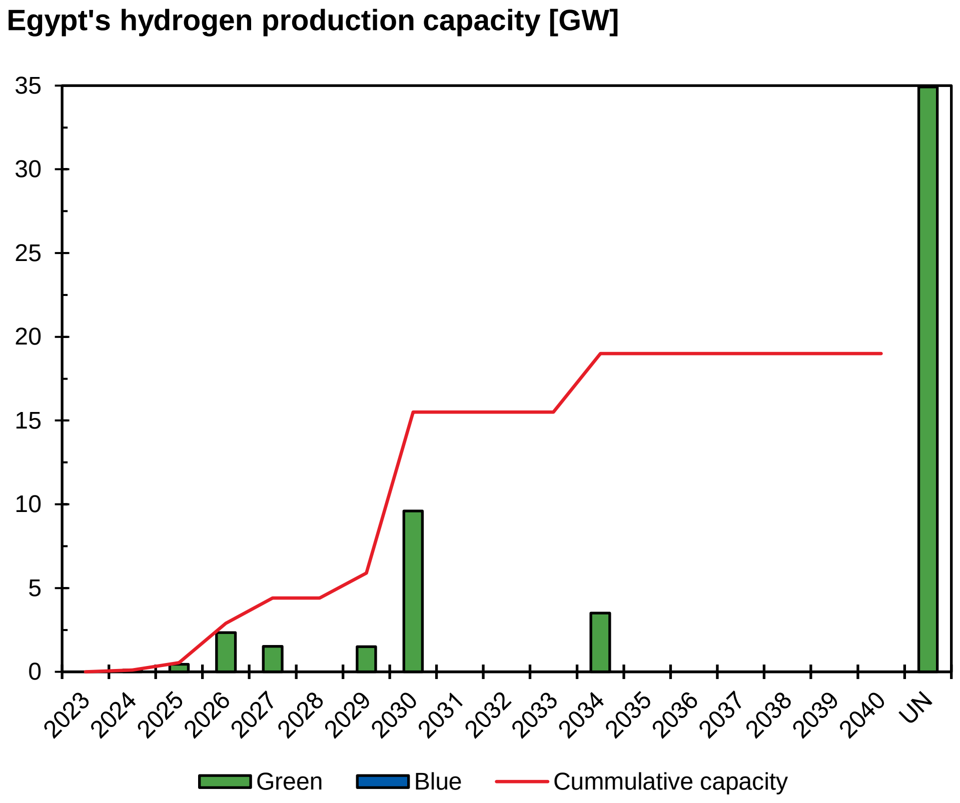
4.1. Egypt
Priority Market Assessment

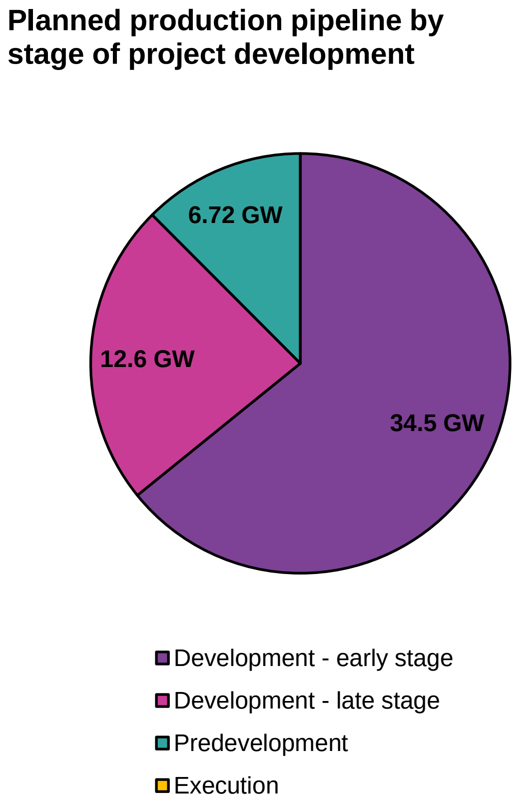
Hydrogen production

Egypt will likely produce most of its low carbon hydrogen via electrolysis. As presented opposite, 100% of the c. 54 GW pipeline is green production. While Egypt benefits from substantial renewable resources, the market struggles with water scarcity, representing a threat to their hydrogen ambitions[1]. Electrolysers require a significant feedstock of purified water[2]. One solution is the development of electrolysers that can operate with lower quality water, or even seawater. A Scottish company, Aqualution, are actively conducting R&D in the area[3]. This represents at strategic opportunity; however, water treatment is generally considered to be a low value component of the value chain.

Egypt's production pipeline is nascent. As presented opposite, over 40 GW is in pre- or early stage-development, while around 35 GW has not announced (or set) a commissioning date. This means that opportunities are likely to initially centre around services, such as engineering design or project management. Moreover, earlier stage projects are less likely to have procured the full range of required services, solutions, and products. Early engagement could secure high-value opportunities at project execution, such as commissioning, installation, or equipment. However, this does introduce some risk; less developed projects are more prone to cancellations.

While not captured in the data, there may be some opportunities around retrofitting existing SMR plants with carbon capture equipment.





Egypt's hydrogen production capacity, including annual additions by technology, cumulative capacity, and the government's 2030 production target (left) and by stage of project development (right).
Source: BloombergNEF and Arup assessment.

1. Positioning Egypt as a Global Green Hydrogen Leader - Meeting Egypt's Environmental Challenges - Carnegie Endowment for International Peace
2. Water treatment for green hydrogen: what you need to know (hydrogentechworld.com)
3. Green hydrogen: How Scotland is meeting electrolyser demand (power-technology.com)

4.1. Egypt
Priority Market Assessment

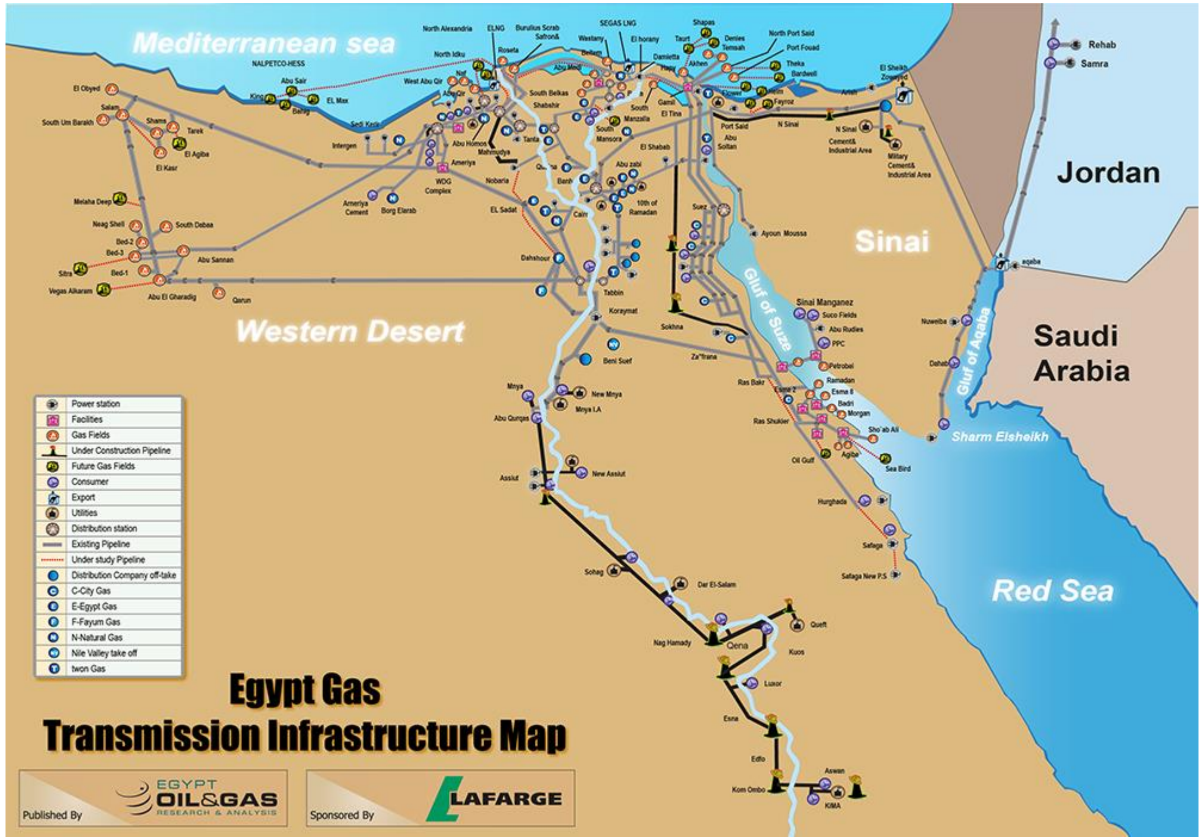
Hydrogen distribution

Egyptian hydrogen production will likely be co-located with demand. It is expected that production will mostly be located at industrial sites, which will likely be the primary users[1]. This will reduce the need to distribute large volumes of hydrogen over longer distances, and means that smaller-capacity, dedicated pipelines or tube trailers will likely be employed within industrial centres. However, export plans and the focus on green hydrogen (requiring large quantities of water and renewable power), mean that co-location may not always be possible.

Distribution over greater distances (or larger quantities) will likely be via larger-capacity pipelines. Egypt has an established gas transmission network (presented opposite) that could be used for hydrogen distribution[1]. This would require an audit of existing pipelines, followed by upgrades to facilitate the transmission of 100% hydrogen. This may be combined with building new stretches of pipeline, where a segment of the supply chain is not met by the current transmission network.

Opportunities for Scottish companies in the distribution segment will focus on solutions and services relating to upgrading or building new transmission pipelines. For example, certification of materials for use with 100% hydrogen will be of strategic value. Products will likely be supplied from in-market capability, such as steel production.

Publication of Egypt's hydrogen strategy will provide more clarity on the likely method of hydrogen distribution and will provide more certainty around the opportunities for Scottish companies.



Egypt's national gas transmission network.

Source: Egypt Gas Transmission Infrastructure Map | Egypt Oil & Gas (egyptoil-gas.com)

1. Egypts-Low-Carbon-Hydrogen-Development-Prospects-ET04.pdf (oxfordenergy.org)

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4.1. Egypt
Market Review

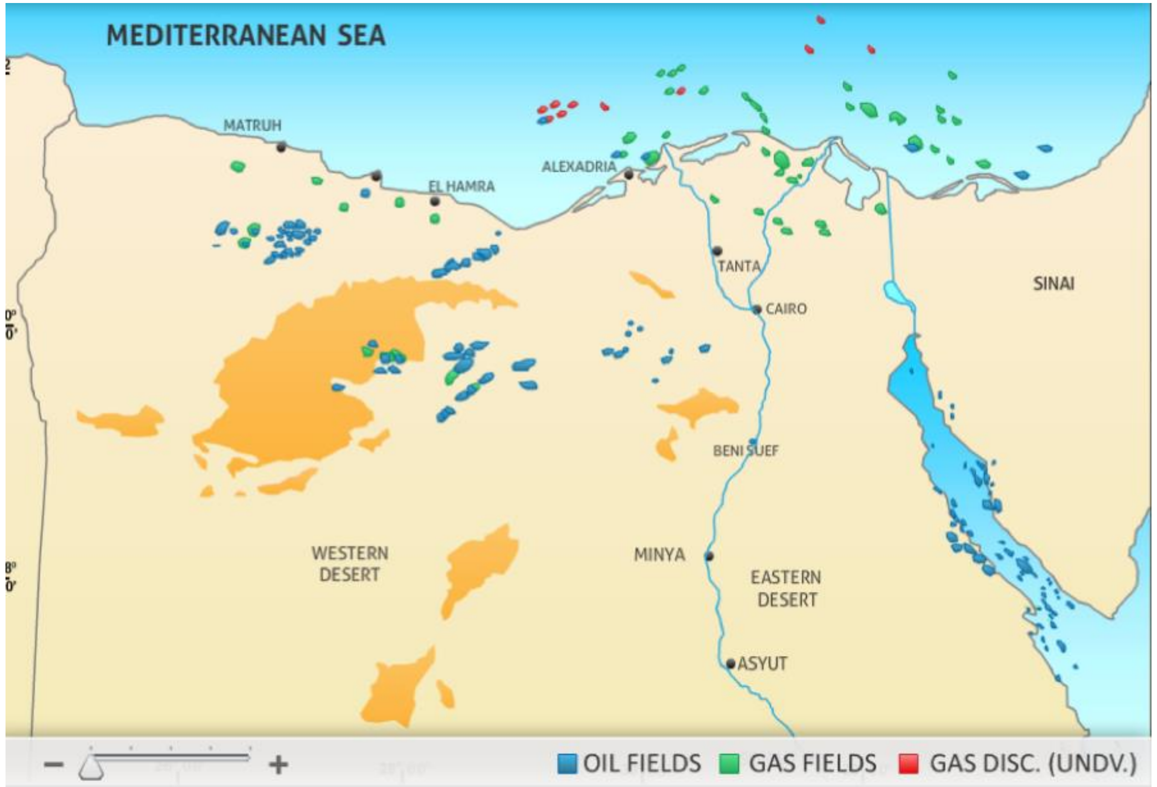
Hydrogen storage

Hydrogen storage plans in the Egyptian market are currently unclear, however there are several available options. The preferred method to store large volumes of hydrogen is geological, usually in salt or rock caverns. However, there is limited data available relating to salt and rock caverns in the market[1]. This means it is not possible to assess if these would be viable options. Alternatively, Egypt could utilise its depleted oil and gas fields, presented opposite. However, this option is the most expensive and has numerous associated technical challanges[1].

At smaller volumes, pressurised storage vessels are a potential option, particularly for buffer storage at industrial sites and in the short-term for smaller projects. Opportunities for Scotland will likely focus on exporting storage vessels to the market. However, the size of this opportunity may be limited.

At this stage, storage as liquid ammonia is a likely option for Egypt. Egypt has experience and existing infrastructure for ammonia making it an appealing option, along with the vector's alignment with export[1]. However, the extensive in-market capability limits gaps within the supply chain and any opportunity for Scottish companies.

Hydrogen storage in Egypt represents an uncertain, and likely limited, market opportunity. As the market matures, along with publication of national strategy, more opportunities may become clear.



Map of Egyptian oil and gas fields.

Source: Outline map of commercial hydrocarbon fields in Egypt (from A.R.E.... | Download Scientific Diagram (researchgate.net)

1. Egypts-Low-Carbon-Hydrogen-Development-Prospects-ET04.pdf (oxfordenergy.org)

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4.1. Egypt
Priority Market Assessment

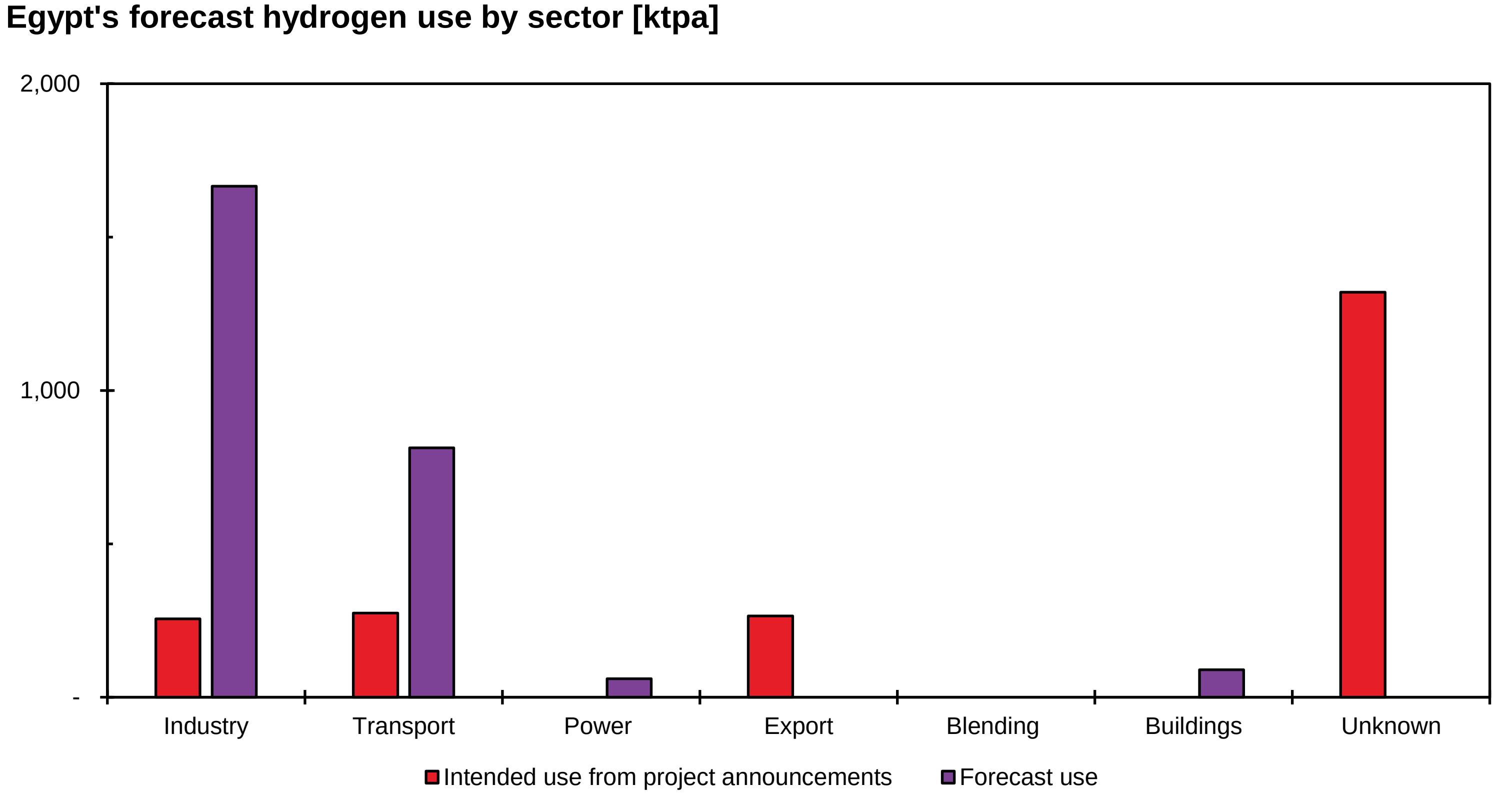
Hydrogen use

Egypt will likely use hydrogen primarily within industrial sectors. This is forecast to capture over 60% of hydrogen demand as assessed, while it captures over 30% of the intended use announced by projects. This is consistent with Egypt's current use of grey hydrogen centring around ammonia production, steel production, and refining. However, this represents a limited opportunity due to the maturity of the sector and resulting in-market capability.

Transport is likely to be the second largest use sector, forecast to capture over 30% of hydrogen demand. This assessment may underpredict potential hydrogen use in transport, as the sector's carbon intensity is likely below the global average due to the use of compressed natural gas in vehicles. While Egypt's strategy has not been published, it has potential to include the conversion of Egypt's compressed natural gas fleet to hydrogen. This is an emerging sector and, as such, likely represents a significant opportunity. Scotland would be well positioned to support the roll out of hydrogen refuelling infrastructure with little in-market competition. Moreover, Egypt may pivot its automotive sector to produce fuel cell electric vehicles. Demand will likely include bunkering fuels for shipping; however, Scotland is less well positioned to capitalise on these opportunities.

Hydrogen may also play a role in Egypt's power sector, namely as an energy storage medium. However, this makes up a small proportion of forecast demand and no projects have announced this as the intended use sector.

Opportunities in the export sector are likely to be limited.



Egypt's forecast hydrogen use – based on announcements from projects (red) and an assessment by Arup (purple).

Source: Arup assessment of hydrogen demand (purple) and project data from BloombergNEF (red).

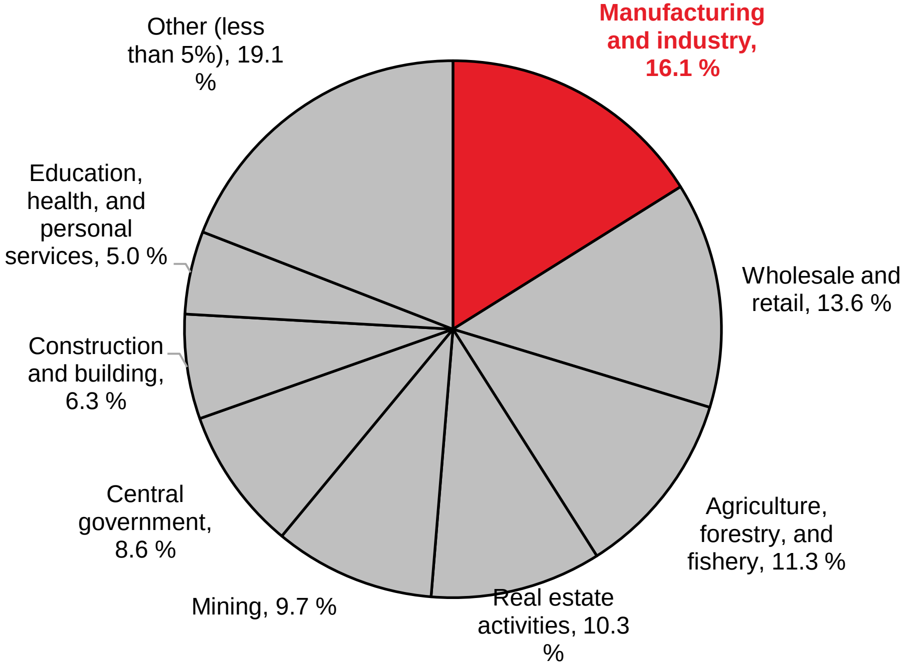
4.1. Egypt
Priority Market Assessment

Wider economy

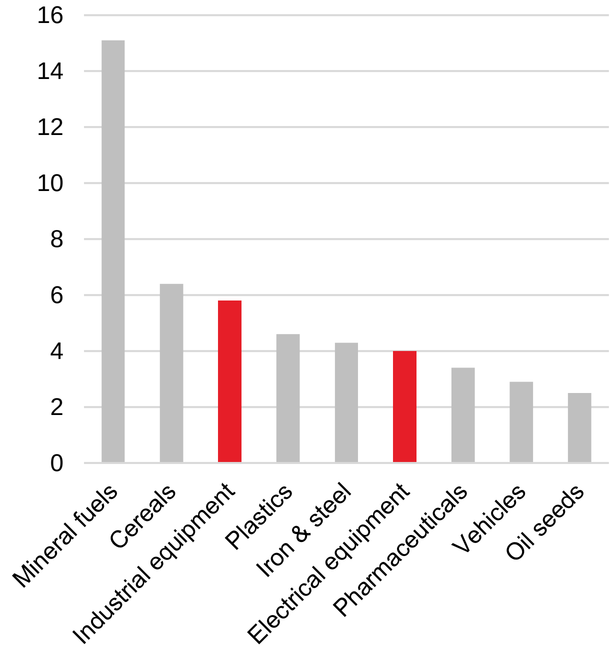
The manufacturing and industrial sector is the largest contributor to Egypt's GDP, as highlighted opposite. While this sector is generally applicable to delivering hydrogen sector ambitions, in Egypt's case it is not. The largest share of manufacturing revenue is generated from textiles and food products[1]. High value and strategically important products, such as industrial and electrical equipment (e.g., compressors, heat exchangers, transformers, etc.) are not manufactured in the market. As highlighted opposite, these are two of the top ten imports to the market. This is a gap within the supply chain and represents an opportunity for Scottish companies. However, the UK is not a major importer to the market and would need to compete with established importers, such as Germany and China[2].

Egypt's gross domestic spending on R&D amounted to 1.7% of its GDP in 2022, lagging the OCED average and UK[3,4,5,6]. This is regarded in literature as major challenge to Egypt's hydrogen ambition; a lack of a viable knowledge base and skills will hamper progress[7]. Furthermore, scientific and technical activities represented one of the smallest shares of employment[8]. This represents an opportunity for Scotland to export expertise and skills derived from the oil and gas sector and early involvement in low carbon hydrogen projects. This will primarily centre around solutions and services and could include engineering services, project management, commissioning, and installation. However, several agreements have already been signed by international companies, increasing competition[9].

Egypt's GDP by sector, 2020



Egypt's top 10 imports [$bn]



Egypt's GDP by sector and top 10 imports

Sources: Egypt: GDP by sector 2019-2020 | Statista (left) and Egypt's Top Imports 2022 (worldstopexports.com) (right)

1. What Major Products Does Egypt Manufacture? (reference.com)
2. Egypt - Trade, Nile, Deserts | Britannica
3. Egypt: domestic expenditure on R&D 2020-2022 | Statista
4. Egypt GDP (tradingeconomics.com)
5. OECD Main Science and Technology Indicators – OECD
6. Research and development spending - House of Commons Library (parliament.uk)
7. Positioning Egypt as a Global Green Hydrogen Leader - Meeting Egypt's Environmental Challenges - Carnegie Middle East Center - Carnegie Endowment for International Peace (carnegie-mec.org)
8. Egypt: employment by sector 2020 | Statista
9. COP27 - Egypt Signs Eight Framework Agreements for Hydrogen Projects, Including an $8 Billion Green Hydrogen Factory - Hydrogen Central (hydrogen-central.com)

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4.1. Egypt
Priority Market Assessment

A summary of the key strengths, weaknesses, opportunities and threats for Scotland to export hydrogen supply chain capability to Egypt are set out below.

Strengths	Weaknesses	Opportunities	Threats
• Lower in-market capability due to industries that are not well suited to support delivery of hydrogen ambition. • Very supportive government position on hydrogen, with a strategy in preparation that will likely provide targets and funding. • Strong political, trade, and economic ties with the UK.	• Level of uncertainty and associated risk due to the early-stage nature of projects and lack of a published strategy. • Lack of transparency around tenders. • Lack of adequate intellectual property protections. • Complex regulatory environment. • Delays in payments. • Existing production of grey hydrogen for industry, indicating some level of hydrogen capability.	• High value products (such as compressors and transformers) are a gap in the supply chain, which could be met by Scottish companies. • Hydrogen use in transport is a nascent sector; Scotland would be well positioned to deliver products, solutions, and services to the segment, namely hydrogen refuelling infrastructure, with little in-market competition. • Services and solutions relating to project development and execution; perceived lack of skills and expertise within the market.	• There are several prominent companies and developers that have agreements with the Egyptian government; potential competition with established suppliers. • Other markets, such as Germany and China, have an established presence exporting to the market.

Section 4.2.

Chile

4.2. Chile
Priority Market Assessment

Hydrogen Outlook

Chile is aiming to become a world leader in green hydrogen production and set an ambitious hydrogen strategy in 2020 to achieve 5 GW electrolyser hydrogen capacity by 2025 and 25 GW production by 2030[1]. The strategy projects that Chile could produce up to 1.6 Mtpa of green hydrogen and become the leading low-cost exporter by 2040.

Chile's hydrogen strategy is focused on its abundant domestic renewable resource, such as the Atacama desert which has the highest solar irradiance on the planet, and powerful onshore wind in Patagonia. Chile is looking to use this significant renewable capacity to produce the cheapest green hydrogen, the strategy has set a target of $1.5/kg by 2030. There are similarities to Scotland's ambitions to produce green hydrogen from plentiful renewable resource, and therefore there is opportunity to share knowledge and skills around pairing green hydrogen projects with renewables and achieving cost reductions through both technology innovation and business models.

Hydrogen demand in Chile is expected to be driven by displacing expensive fossil fuels in the mining, transport and agriculture industries. There are also more innovative opportunities, such as production of green copper. The strategy also strongly focuses on export of green liquid hydrogen, green ammonia and low carbon synthetic fuels, with the cheap, zero-carbon production being a differentiating factor on the international market. The hydrogen strategy projects that approximately 70% of the hydrogen produced in Chile in 2050 will be exported[1]. The International Renewable Energy Agency has identified Chile, Morocco and Namibia as countries with strong potential to be future green hydrogen exporters[2].

At present, Chile does not produce any hydrogen at an industrial scale. However, the hydrogen strategy aims to scale up demand over three 'waves'. Wave 1 will be focused on hydrogen for domestic transport, mining haul trucks, ammonia and oil refinery use in addition to blending in the gas grid. Waves 2 and 3 will expand to ammonia and hydrogen exports and ammonia for shipping. These demand cases could align well with Scotland's research and early project experience, from hydrogen buses deployed in Aberdeen to the H100 Fife trial of hydrogen in the gas network.

Chile's development agency, CORFO, committed $50mn in January 2022 to finance the development of six green hydrogen pilot projects, a total capacity of 396 MW. However, despite having a hydrogen project pipeline of over 20 projects, the majority have not yet reached financial investment decision. There are plans to open a Green Hydrogen Finance Programme (PFCH2V) in Q3 2024, worth $72mn, to assist projects with capex costs and help projects reach financial close. This fund is backed by the European Investment Bank, World Bank and International Development Bank[3].

25GW

targeted by 2030

$770m

available in public funding

1. https://energia.gob.cl/sites/default/files/national_green_hydrogen_strategy_-_chile.pdf
2. https://www.irena.org/Digital-Report/Geopolitics-of-the-Energy-Transformation
3. https://www.hydrogeninsight.com/policy/chile-unveils-728m-fund-to-de-risk-green-hydrogen-projects-backed-by-european-and-us-banks/2-1-1466607

4.2. Chile
Priority Market Assessment

Hydrogen Production

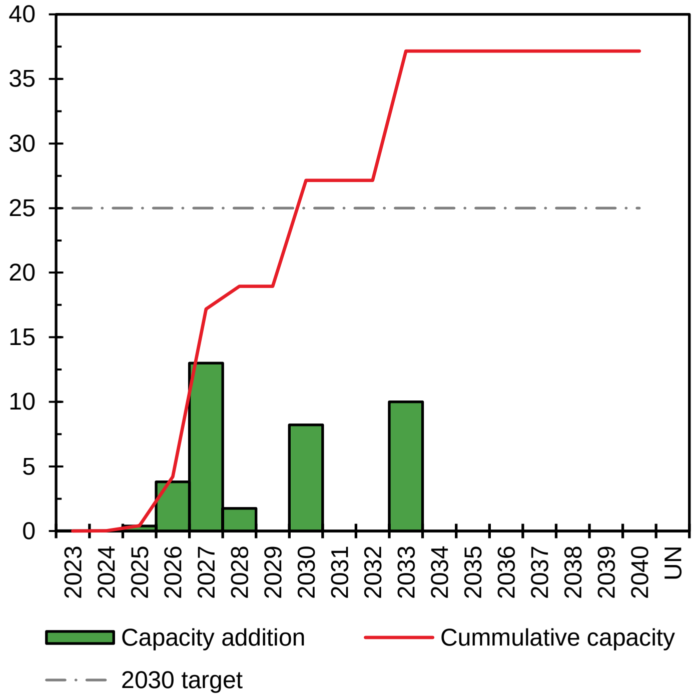
The Chilean market will be dominated by green hydrogen production, as the current planned pipeline is fully captured by electrolytic production. This is reflective of Chile's excellent renewable energy resource. This means that the production segment of the supply chain will be dominated by any products, solutions, and services that relate to green hydrogen.

Chile has a strong pipeline of 26 production projects, with 28 GW of electrolyser capacity forecast to be commissioned by 2030 and 38 GW by 2050[1]. This pipeline exceeds the government 2030 target production capacity by 3 GW. However, most projects are still at early planning stages and the current pipeline of planned projects shows a significant step change in capacity in 2027, followed by steady growth to 2050.

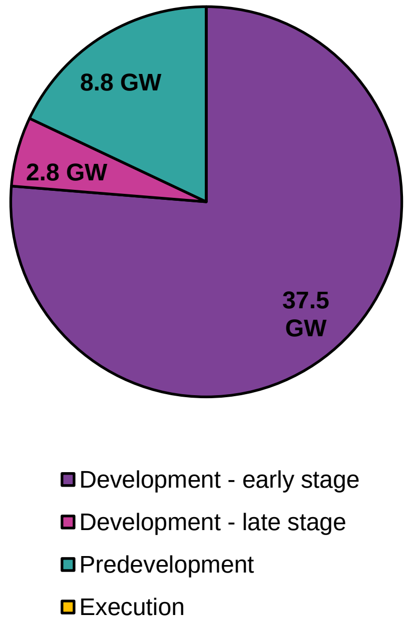
Therefore, in the near-term, this segment of the market will mostly require services. It will not be until the latter half of the decade, where a significant demand for products and solutions could be anticipated. Based on the pipeline for Chile, there will likely be significant requirement for equipment, EPC skills and hydrogen offtakers towards the mid-late 2020s to achieve development of projects.

The six publicly funded green hydrogen pilot projects will form some of the first of Chile's hydrogen production and most are expected to be developed by 2025. The companies are Enel Green Power (1.25 MW electrolyser capacity), Air Liquide (80 MW), Engie (26 MW), GNL Quintero (10 MW), CAP (20 MW), and Linde (20 MW)[2]. There are currently two operational plants in Chile, Anglo American Las Tortolas Copper Plant which provides hydrogen to a forklift crane and a fuel cell, and HIF Haru Oni which uses hydrogen to produce eFuels.

Chilian hydrogen production capacity [GWe]



Planned production pipeline by stage of project development



Chile's hydrogen production capacity, including annual additions by technology, cumulative capacity, and the government's 2030 production target (left) and by stage of project development (right).

1. BNEF Hydrogen Production database https://www.bnef.com/interactive-datasets/2d5fb18e5f001461?data-hub=2d5fb18e5f001462&tab=Electrolyzer%20Capacity
2. https://gh2.org/countries/chile

4.2. Chile
Priority Market Assessment

Hydrogen Use

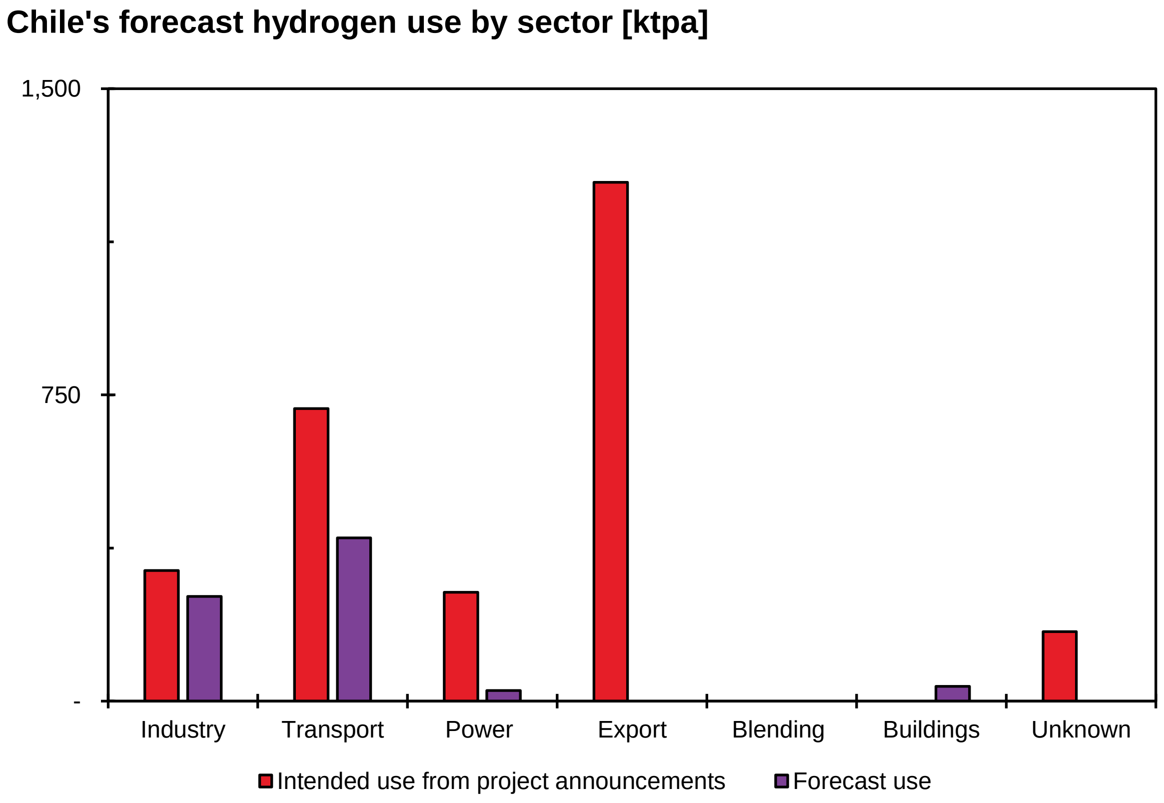
Chile's hydrogen strategy primarily targets export, industry, transport, and power, as reflected within their hydrogen strategy[1]. This is broadly consistent with the demand forecast and the intended use by project, presented opposite. In both cases, industry and transport are the primary in-market use cases.

Use within the industrial sector will likely centre around displacing current fossil fuel-based consumption. This is predominately within mining and raw material production and agriculture, both which are relatively mature sectors within the Chilean market. This suggests that there is limited opportunity within this subsegment of the supply chain.

Use within the transport sector will likely centre around HGVs, mining haul trucks and buses. The first hydrogen fuel cell bus was launched in October 2023[2]. Hydrogen ready vehicles and refuelling infrastructure is a crucial aspect of hydrogen use within transport and a rapid scale up will be required to achieve growth in hydrogen transport, which is an area that Scotland could capitalise on.

The hydrogen strategy also mentions blending in the gas grid, and a pilot project was commissioned in 2022 by Chilean gas distributer Gasvalpro which injects up to 20% hydrogen in the gas network for 2,000 homes[3].

Chile is looking to become one of the biggest exporters of hydrogen globally, and is primarily looking to export as green ammonia. Challenges around transport logistics and port infrastructure, in addition to sufficient hydrogen product, will be key to realising export ambitions.



Chile's forecast hydrogen use – based on announcements from projects (red) and an assessment by Arup (purple).

Source: Arup assessment of hydrogen demand (purple) and project data from BloombergNEF (red).

1. https://energia.gob.cl/sites/default/files/national_green_hydrogen_strategy_-_chile.pdf
2. https://www.angloamerican.com/our-stories/innovation-and-technology/driving-sustainability-anglo-american-backed-hydrogen-bus-launches-in-chile
3. https://www.fiorentini.com/en/news/inaugurated-the-first-hydrogen-blending-station-by-pietro-fiorentini/#:~:text=Commissioned%20by%20Gasvalpro%2C%20the%20oldest,reaching%20more%20than%202%2C000%20homes.

ARUP

4.2. Chile
Priority Market Assessment

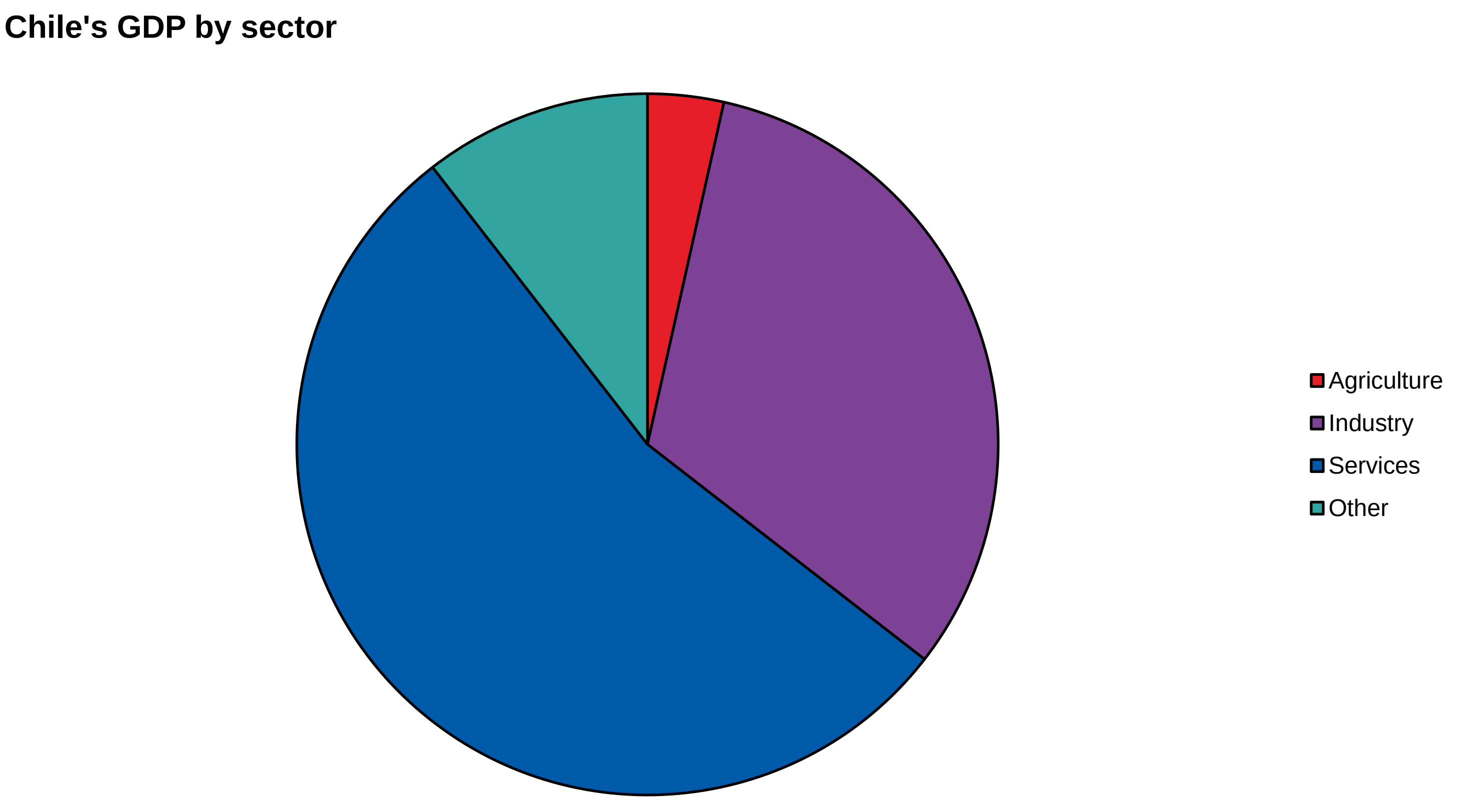
Wider Economy

In the 20th century, Chile underwent rapid growth and now has a high-income economy, largely based on mining (including copper, lithium, silver and salt), agriculture and tourism. Hydrogen is planned to be used primarily in the mining and agriculture sectors.

Mining is one of the largest industries in Chile, and the country is the highest copper producer globally. The government is interested in exploring options to use hydrogen to decarbonise mining operations such as heavy machinery, trucks and forklifts to produce 'green copper'.

Agricultural sectors include fishing, forestry and farming. Chile's main exports include wine, fruit, dairy, salmon, pork, poultry, and forestry products[1]. Chile has a significant salmon farming industry as the world's second largest producer. Chile's agricultural sectors align well with Scotland, for which agriculture also focuses on fruit, salmon, meat, dairy and forestry, therefore there could be opportunity to export decarbonisation technologies around this sector.

Energy in Chile is primarily sourced from imported coal, oil and gas with some hydroelectricity and biofuels. Renewable energy is a growing industry, and Chile has vast renewable energy potential amounting to 70 times the current installed capacity[2]. Notably, the Atacama desert has the highest long term solar irradiance in the world. As a country that has traditionally imported energy, Scotland's oil and gas sector may provide complimentary skills and expertise to Chile's energy sector.



Chile's gross domestic product by sector for 2022

Source: Chile - share of economic sectors in the gross domestic product 2022 | Statista

1. https://www.trade.gov/country-commercial-guides/chile-agricultural-sector
2. https://energia.gob.cl/sites/default/files/national_green_hydrogen_strategy_-_chile.pdf

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4.2. Chile
Key Findings

A summary of the key strengths, weaknesses, opportunities and threats for Scotland to export hydrogen supply chain capability to Chile are set out below.

Strengths	Weaknesses	Opportunities	Threats
• Supportive government and ambitious hydrogen strategy in place – 5 GW electrolyser hydrogen capacity by 2025 and 25 GW production by 2030, along with financial backing. • Good political alignment, with trade agreements in place. • Strong pipeline of green hydrogen projects looking to capitalise on plentiful renewable resource. • Supply chain is at early stage with only two projects operational. • Open to international collaboration, many hydrogen projects already have international developers involved.	• Chile's mining industry may already provide some of the engineering and innovation capabilities required for the hydrogen sector as they look to incorporate renewable energy in their sites. • Water scarcity for electrolysis in some areas may be a barrier to hydrogen project development. • Success breaking into the market in Chile generally requires in-country presence or partners.	• Opportunity to share knowledge and skills around pairing green hydrogen projects with renewables and achieving cost reductions through both technology and business models. • Chile's planned use cases could align well with Scotland's research and experience, from early hydrogen buses deployed in Aberdeen to the H100 trial of hydrogen in the gas network in Fife. • High level of privatisation in Chile provides opportunity for Scottish companies to export capability. • Chile currently imports nearly all its energy supply, therefore there is opportunity to export Scotland's renewables and oil and gas industry expertise relevant to the hydrogen industry.	• Current economic uncertainty postponing investment. • High degree of competition due to relatively small market size. Several international companies already involved in Chilean hydrogen projects. • Chance that hydrogen activity in Chile won't meet ambition – challenges around offtake, transport and export infrastructure. • Could see Scotland as a competitor in hydrogen export to Europe.

Section 4.3.

India

ARUP

4.3. India
Priority Market Assessment

Hydrogen Outlook

The Indian government is aiming to become a hub for green hydrogen and green ammonia production. Hydrogen is seen as a key enabler for boosting energy security, reducing reliance on fossil fuels and providing long duration storage of renewable energy. In 2022, India set a National Green Hydrogen Mission which aims to achieve a hydrogen production capacity of 5 Mtpa by 2030, with a renewable energy capacity addition of 125 GW[1].

India's hydrogen mission is focused around reducing emissions and reliance on fossil fuels, in addition to developing manufacturing capability, support research and development, creating jobs and attracting investment. Subcomponents include:

- Two financial incentive mechanisms targeting domestic manufacturing of electrolysers and production of green hydrogen.
- Supporting pilot projects and identifying regions to develop large scale hydrogen hubs.
- Public-private partnership framework for research and development projects.
- Skills development projects.

The demand for hydrogen is expected to see a five-fold jump to 28 Mtpa by 2050 where 80% of the demand is expected to be met by green hydrogen[1]. It is expected to support industrial sectors, such as steel, fertilizer and petrochemical production, heavy-duty transport with longer trip range such as buses and trucks, and long duration storage of renewable energy. India is also looking at becoming a hydrogen exporter to Japan, South Korea and Europe.

Under the Strategic Interventions for Green Hydrogen Transition Programme (SIGHT), $2.13bn in funding is planned to be allocated targeting domestic manufacturing of electrolysers and green hydrogen production. The World Bank recently approved $1.5 billion in financing for the Indian government to scale up green hydrogen and renewable energy[2].

5 Mtpa

targeted by 2030

$2.13bn

available in public funding

1. https://www.india.gov.in/spotlight/national-green-hydrogen-mission#:~:text=The%20National%20Green%20Hydrogen%20Mission,Green%20Hydrogen%20and%20its%20derivatives
2. https://www.worldbank.org/en/news/press-release/2023/06/29/world-bank-approves-1-5-billion-in-financing-to-support-india-s-low-carbon-transition#:~:text=The%20financing%20will%20help%20India,large%20economies%20in%20the%20world.

ARUP

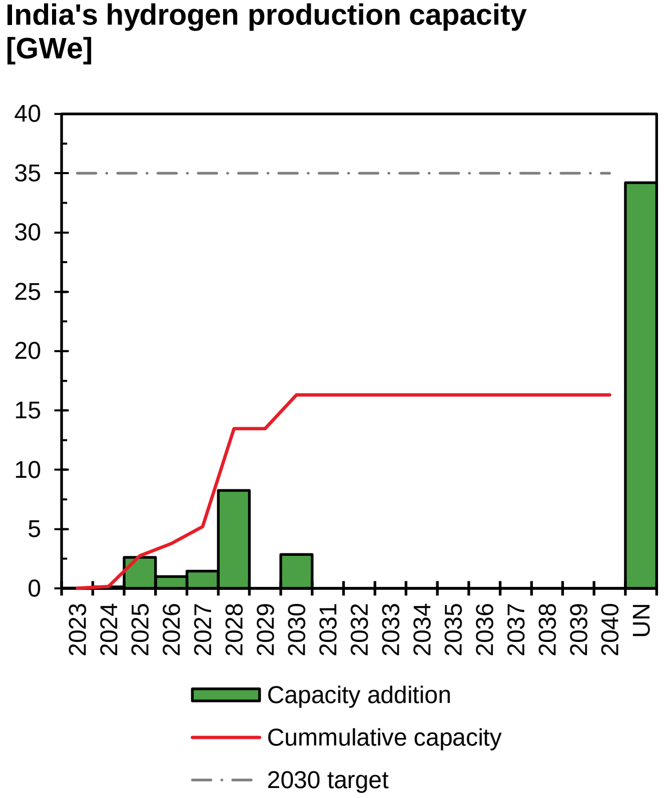
4.3. India
Priority Market Assessment

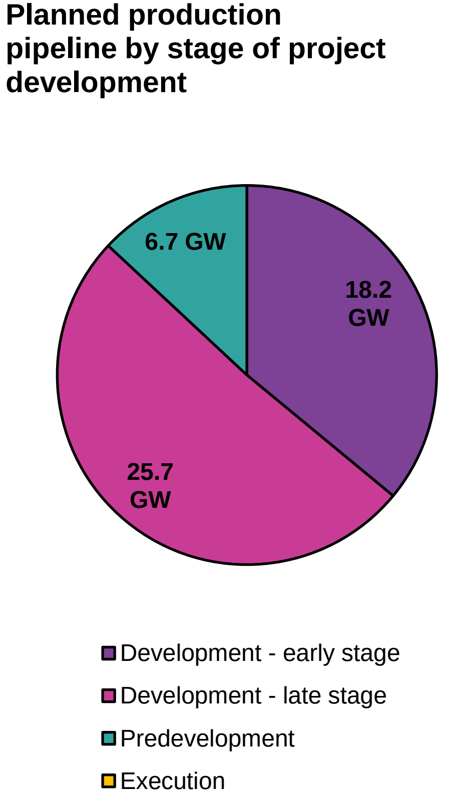
Hydrogen Production

The Indian market will be dominated by green hydrogen production, as the current planned pipeline is fully captured by electrolytic production. This means that this the production segment of the supply chain will be dominated by any products, solutions, and services that relate to green hydrogen.

India has a strong pipeline of 30 production projects, with over 2 Mtpa of capacity forecast to be commissioned by 2030[1]. There is opportunity for a significant volume of new hydrogen capacity yet to be announced, in order to meet the Indian government's target of 5 Mtpa by 2030. As illustrated opposite, the current pipeline of planned projects shows a step change in capacity from 2028 onwards. Therefore, in the near-term, this segment of the market will mostly require services. It will not be until the latter half of the decade, where a significant demand for products and solutions could be anticipated.

The first hydrogen projects are expected to be commissioned in 2024. There are two planned large-scale production projects: ACME Kujanga (21 GW) with 1.1 Mtpa hydrogen production and ANIL Khvada (7.7 GW) expected commissioning in 2027 with 1 Mtpa hydrogen production. Many hydrogen project developers are large Indian industrial companies, including ACME Group, Adani Group, GAIL India and Indian Oil Corp Ltd. This reflects India's strong industrial and manufacturing heritage and the ability to grow capability in the hydrogen sector and may provide a challenge for Scotland to provide project development services.





India's hydrogen production capacity, including annual additions by technology, cumulative capacity, and the government's 2030 production target (left) and by stage of project development (right).

1. BNEF Hydrogen Production database https://www.bnef.com/interactive-datasets/2d5fb18e5f001461?data-hub=2d5fb18e5f001462&tab=Clean%20Hydrogen%20Volume

ARUP

4.3. India
Priority Market Assessment

Hydrogen Use

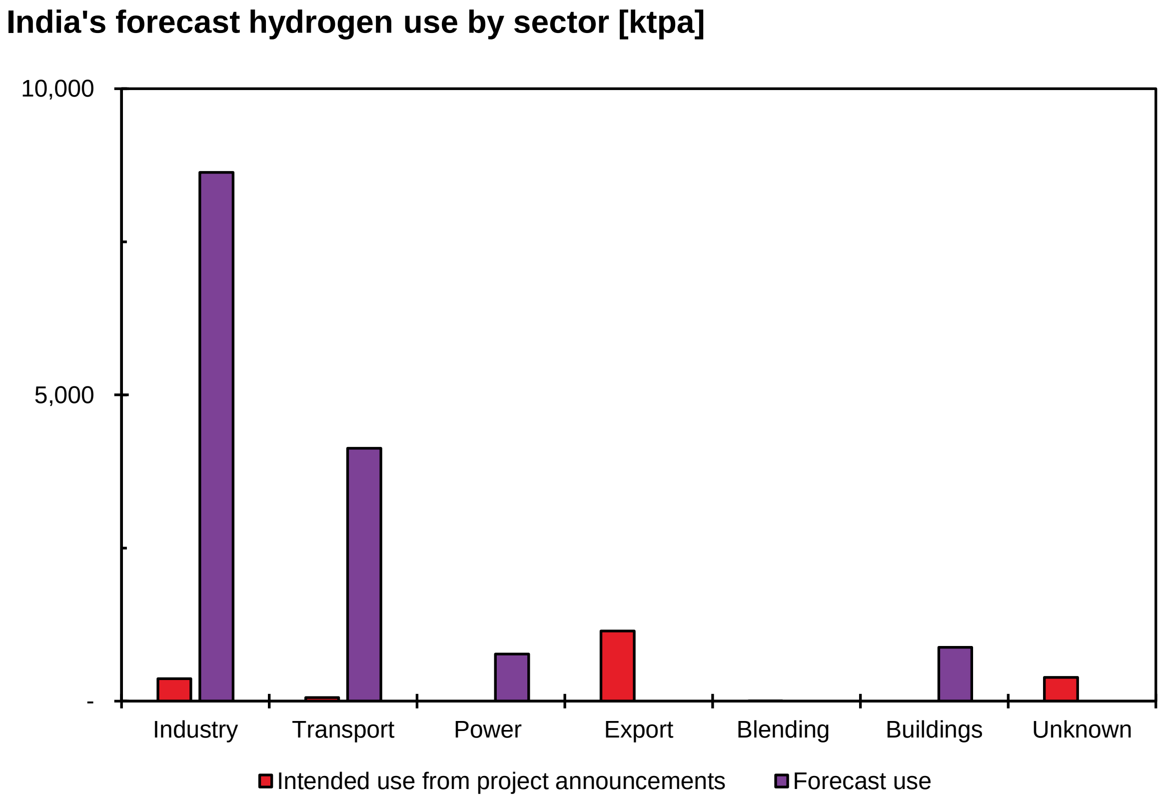
India's hydrogen strategy primarily targets industry, transport, and power, as reflected within their Hydrogen Mission. This is broadly consistent with the demand forecast and the intended use by project, presented opposite. In both cases, industry and transport are the primary use cases.

Hydrogen demand today is approximately 6 Mtpa, and this is expected to grow 5-fold to around 28 Mtpa by 2050[1]. This is primarily driven by India's large industrial sector, including applications such as fertilisers and refining. These applications are expected to expand demand for hydrogen significantly as reliance on fossil fuels is reduced, in addition to demand created by new end-uses such as steel production. India's lack of domestic natural gas supply and high cost of imports could make green hydrogen more competitive than other countries.

Whilst large-scale hydrogen projects are still to become operational, several large industrial companies have shown interest in the green hydrogen space. The Hydrogen Mission is looking to establish supply hubs near demand centres, which are likely to be areas with refineries and fertiliser plants, to reduce transport and storage costs.

India envisions the transport sector to be another key offtaker and hydrogen vehicles have been developed and demonstrated under projects supported by the Indian Government[2]. These include: two fuel cell buses by Tata Motors Ltd.; fifty hydrogen enriched natural gas buses in Delhi by Indian Oil Corporation Ltd; and two hydrogen fuelled Internal Combustion Engine buses by IIT Delhi in collaboration with Mahindra & Mahindra. In addition, progress has been made developing refuelling infrastructure, including two hydrogen refuelling stations at the Indian Oil R&D Centre and National Institute of Solar Energy.

In the power sector, hydrogen is expected to be used for long duration storage of renewable energy.



India's forecast hydrogen use – based on announcements from projects (red) and an assessment by Arup (purple).

Source: Arup assessment of hydrogen demand (purple) and project data from BloombergNEF (red).

1. https://www.teriin.org/sites/default/files/2020-12/potential-role-hydrogen-india.pdf
2. https://static.pib.gov.in/WriteReadData/specificdocs/documents/2022/mar/doc202232127201.pdf

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4.3. India
Priority Market Assessment

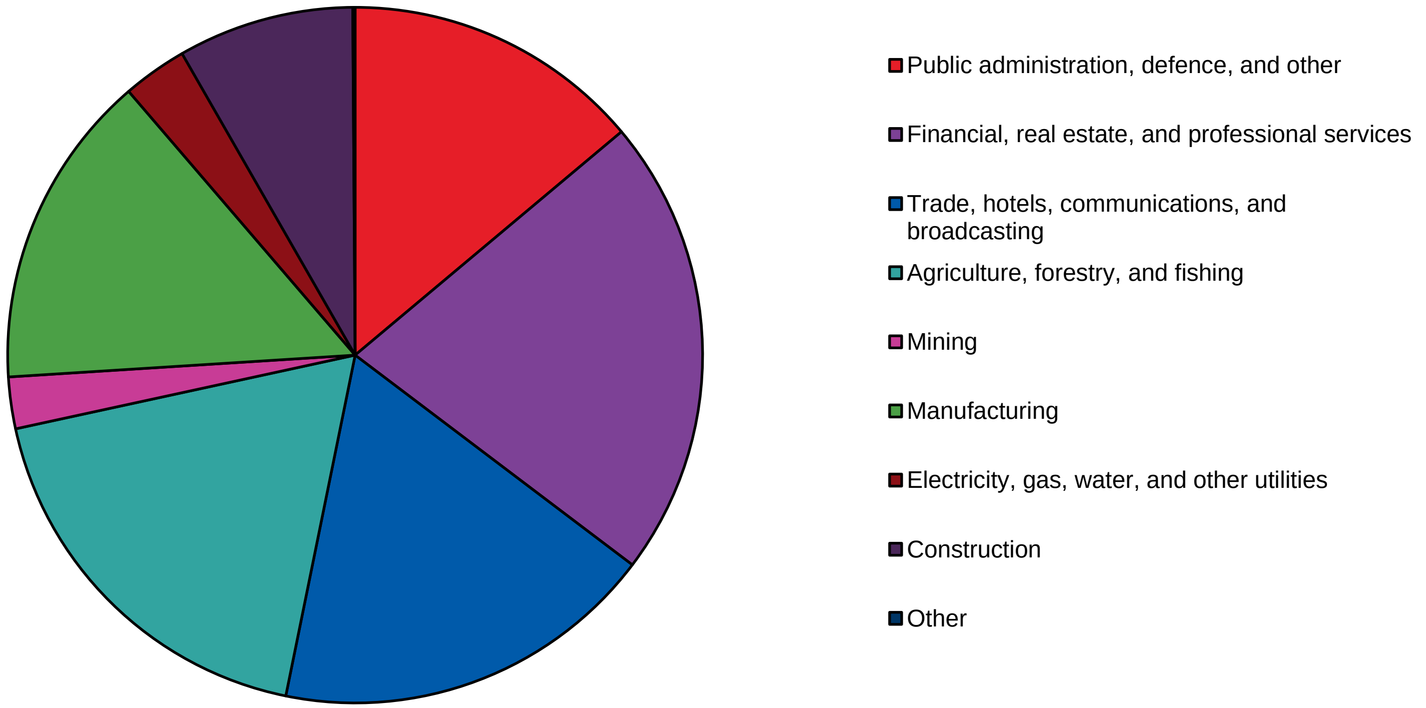
Wider Economy

India has a population of 1.4bn people, becoming the world's most populous country in April 2023. India is one of the world's fastest growing economies, largely based on services, industry (including textiles, chemicals, manufacturing, pharmaceuticals and biotechnology, among others) and agriculture.

Indian corporations in industrial sectors such as information technology, telecommunications, pharmaceuticals, textiles, and engineering, are globally recognised for their innovation and attractiveness. The Indian government encourages the growth of manufacturing and assembly in India and have launched initiatives such as 'Make in India' to incentivise this. As a federal system, power and decision-making are decentralised in India, with differences at the state level in political leadership, governance, regulations and taxation, which can cause some challenges around doing business in India[1].

Energy in India is primarily sourced from coal, oil, gas and traditional biomass. While access to electricity has been achieved for nearly all households, nearly a third have still use traditional fuels for cooking and air pollution is a significant issue. Renewable energy is a growing industry, in particular solar PV has seen significant deployment since 2014.

India's GDP by sector



India's Gross Domestic Product by sector for 2023

Source: India GDP sector-wise 2023 - StatisticsTimes.com

1. https://www.trade.gov/country-commercial-guides/india-market-challenges

4.3. India
Key Findings

A summary of the key strengths, weaknesses, opportunities and threats for Scotland to export hydrogen supply chain capability to India are set out below.

Strengths	Weaknesses	Opportunities	Threats
• Supportive government and ambitious hydrogen strategy in place - 5 Mtpa hydrogen production capacity of by 2030, along with financial backing. • Strong pipeline of green hydrogen projects with demand expected to grow along with population and urbanisation. • First hydrogen projects to be built in 2024 which means supply chain is at early stage.	• Non-transparent or unpredictable regulatory and tariff policies. Differences in governance and regulations at a state level could be challenging to navigate. • India has strong manufacturing and industrial sectors which is likely to provide capabilities required for the hydrogen sector. • Infrastructure development needs could be a risk to hydrogen projects and capacity constraints.	• Most hydrogen projects are being built by large Indian companies, however there could be opportunities for technology or knowledge partnerships. • Primarily transport and hydrogen use, such as refining, could align well with Scotland's experience and capability. • As India looks to upgrade its national power grid, there could be demand for capability in whole system energy solutions, incorporating hydrogen, renewables and smart technology.	• Competition for low-cost manufacturing, services and equipment. • There is a focus from the Indian government on local companies and supply chains – therefore presence in India may be required.

Section 4.4.

Spain

ARUP

4.4. Spain
Priority Market Assessment

Hydrogen outlook

Spain has a clear vision and strategy for developing its hydrogen sector that focuses on the roll out of green hydrogen and is motivated by its energy transition goals. In October 2020, the Spanish Government published the "Hydrogen Roadmap: a commitment to renewable hydrogen" that sets out measures and targets to support growth of green hydrogen through investment and innovation in the field[1]. The roadmap aligns with the EU Hydrogen Strategy for a climate-neutral Europe and the European Recovery Instrument (Next Generation EU), which provide financial support for projects and will support sector growth[2,3].

The strategy focuses on a phased approach to sector growth, with small-scale electrolyser deployment in the short-term, followed by substantial uptake in target industries from 2025, and a net-zero, hydrogen economy by 2050[1]. The measures within the strategy focus on regulatory reform, sectoral impact targets, and innovation, in conjunction with comprehensive funding and investment. It is estimated that €1.5bn is available in public funding, while an additional €8.9bn will being delivered through to 2030[4,1]. This aims to stimulate private investment into the market, with a focus placed on public-private partnerships.

Spain's ambition focuses on the decarbonisation of sectors that are difficult to electrify or are energy intense, alongside promoting energy security and to become more competitive within the wider European market. This is reflected within their sector impact plans that aim to deliver low carbon hydrogen to industry, transport, and power sectors[2].

Spain's hydrogen sector is at a transitional stage. The market has emerged as a clear world leader within the sector, delivering a significant number of pilot projects to date. As of 2022, Spain's national energy company, Iberdrola, had commissioned the largest green hydrogen plant for industrial use, with a 20 MW electrolyser and 100 MW solar PV farm[5]. A further 22 projects have been deployed and another 11 are at FID. Moreover, several initiatives have focused on strengthening the full value chain, such as a partnership between Iberdrola and Cummins on large-scale production[6,7]. This is in conjunction with Cummins' decision to select the market as the location for its GW-scale electrolyser facility, which was scheduled to enter operation at the end of 2023[7].

Spain is strategically located at the crossroads of Europe and Africa. The places Spain in a strong position to facilitate the transmission of hydrogen to demand centres (such as northern Europe) from large scale producers in Africa (such as Morocco). This plays into Spain's plans to become a hub for green hydrogen.

Furthermore, the market is set to become a net exporter by 2050, driven by increasing levels of in-market production and a demand spike across Europe[2].

11GW

targeted by 2030

€1.5bn

available in public funding

1. The Spanish Hydrogen Strategy – WFW
2. focus-on-hydrogen-spains-bid-to-play-a-leading-role-in-new-energy.pdf (cliffordchance.com)
3. Hydrogen and Green Energy Investment bing – Storelectric
4. BloombergNEF, hydrogen
5. Puertollano green hydrogen plant – Iberdrola
6. La Moncloa. 24/05/2021. Sánchez underlines Spain's commitment to becoming the European green hydrogen industrial hub [President/News]
7. Cummins selects Spain for its gigawatt electrolyzer plant & partners with Iberdrola to lead the green hydrogen value chain | Cummins Inc.

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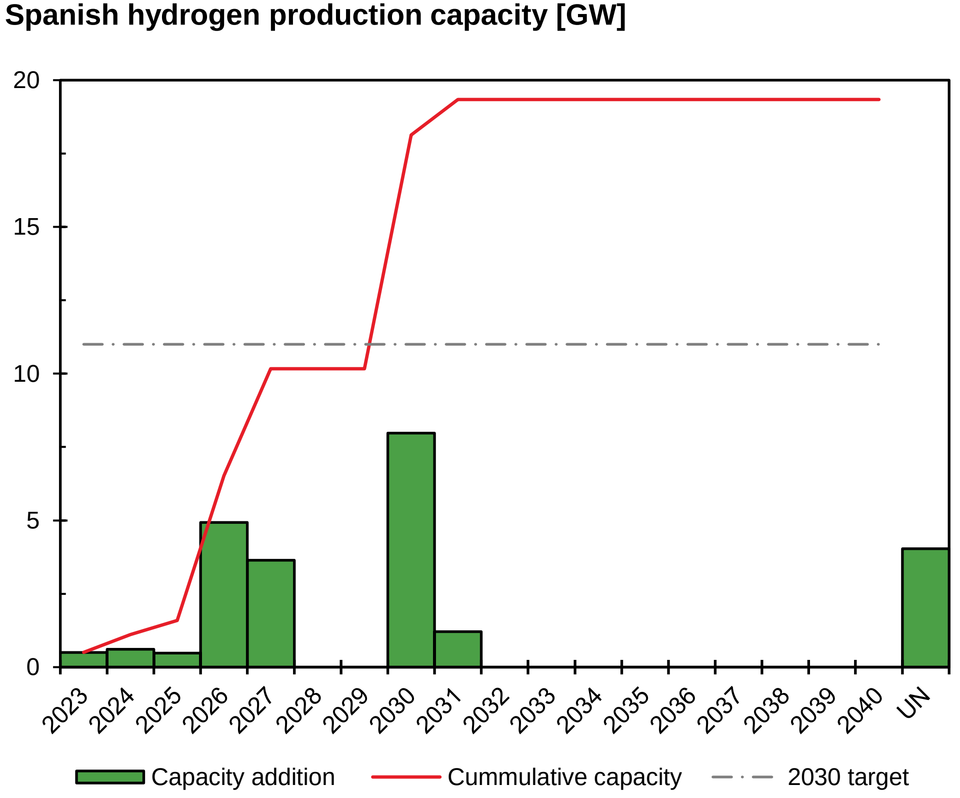
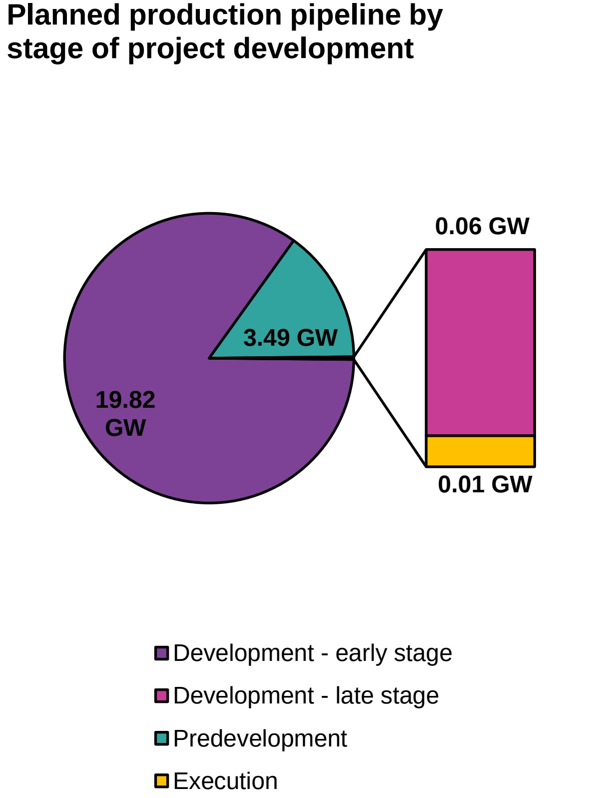
4.4. Spain
Priority Market Assessment

Hydrogen production

Green hydrogen will dominate the Spanish hydrogen market. As presented opposite, 100% of the market is captured by this production method. Access to electrolysers will be crucial to the delivery of these projects. While Spain has plans for in-market electrolyser manufacturing, their manufacturing sector is not well suited to provide subcomponents[1]. This could potentially reduce the nameplate electrolyser manufacturing capacity by up to 70%[2]. There is a significant opportunity here for Scotland to export electrolyser subcomponents to the Spanish market. Langfields, a Scottish company included in the case study section of the report, currently supply to electrolyser OEMs in other markets. Scotland's experience in this area is a clear strength; however, cheaper alternatives and already trusted suppliers are barriers to entry.

A substantial majority of projects are in development. As presented opposite, over 19 GW are currently in early-stage development. While this perhaps limits the opportunity to provide services during project development (as services have likely been procured already), early engagement could secure the involvement of Scottish companies during project execution such as Engineering, Procurement and Construction (EPC) services. This opportunity will centre on solutions, such as mechanical installation, electrical installation, and commissioning, that play to Scotland's strengths from oil and gas experience.





Spain's hydrogen production capacity, including annual additions by technology, cumulative capacity, and the government's 2030 production target (left) and by stage of project development (right).

Source: BloombergNEF and Arup assessment.

1. The Biggest Industries In Spain – WorldAtlas
2. BloombergNEF H1 2023 Hydrogen Market Outlook

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4.4. Spain
Priority Market Assessment

Hydrogen distribution

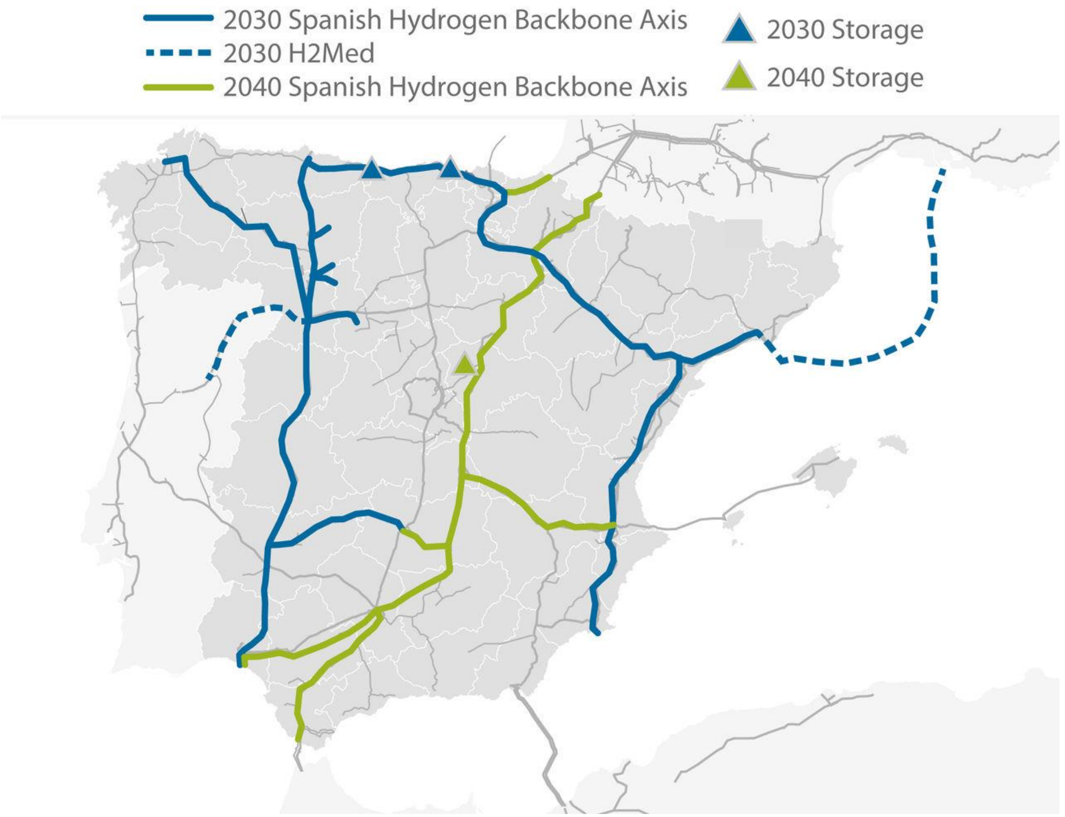
Hydrogen distribution in the Spanish market will be primarily be via pipelines. Engas, which are part of the European Hydrogen Backbone initiative, have proposed comprehensive hydrogen distribution infrastructure in the form of pipeline transmission. This is presented opposite. The project will likely have a substantial capacity, playing a pivotal role in distribution. In November 2023, the project was included in the list of European Projects of Common Interest[1].

The national transmission system will be connected to H2Med – a joint project between Spain, Portugal, and France[1,2]. This aspect will connect Spain to the rest of the European continent.

The use of pipelines also plays into Spain's wider strategy of industrial clusters; i.e. the colocation of demand and supply. Within clusters, dedicated pipelines will likely be used for distribution. For example: at a first of its kind green hydrogen hub located in Asturias, Spain plans to use dedicated pipelines for distribution[3].

Other distribution methods, such as tube trailers, are also likely to play a role. However, they are not considered in this market for a study of this scale.

The widespread use of pipeline distribution represents a potential opportunity for Scotland to leverage oil & gas pipeline construction experience.



Spain's proposed hydrogen transmission infrastructure by Engas in 2030 and 2040.

Source: Engas - Hydrogen Transmission - Enagás (enagas.es)

1. Hydrogen Transmission - Enagás (enagas.es)
2. France, Spain and Portugal agree to build Barcelona-Marseille gas pipeline | Reuters
3. World's first green hydrogen hub to be born in Asturias (investinspain.org)

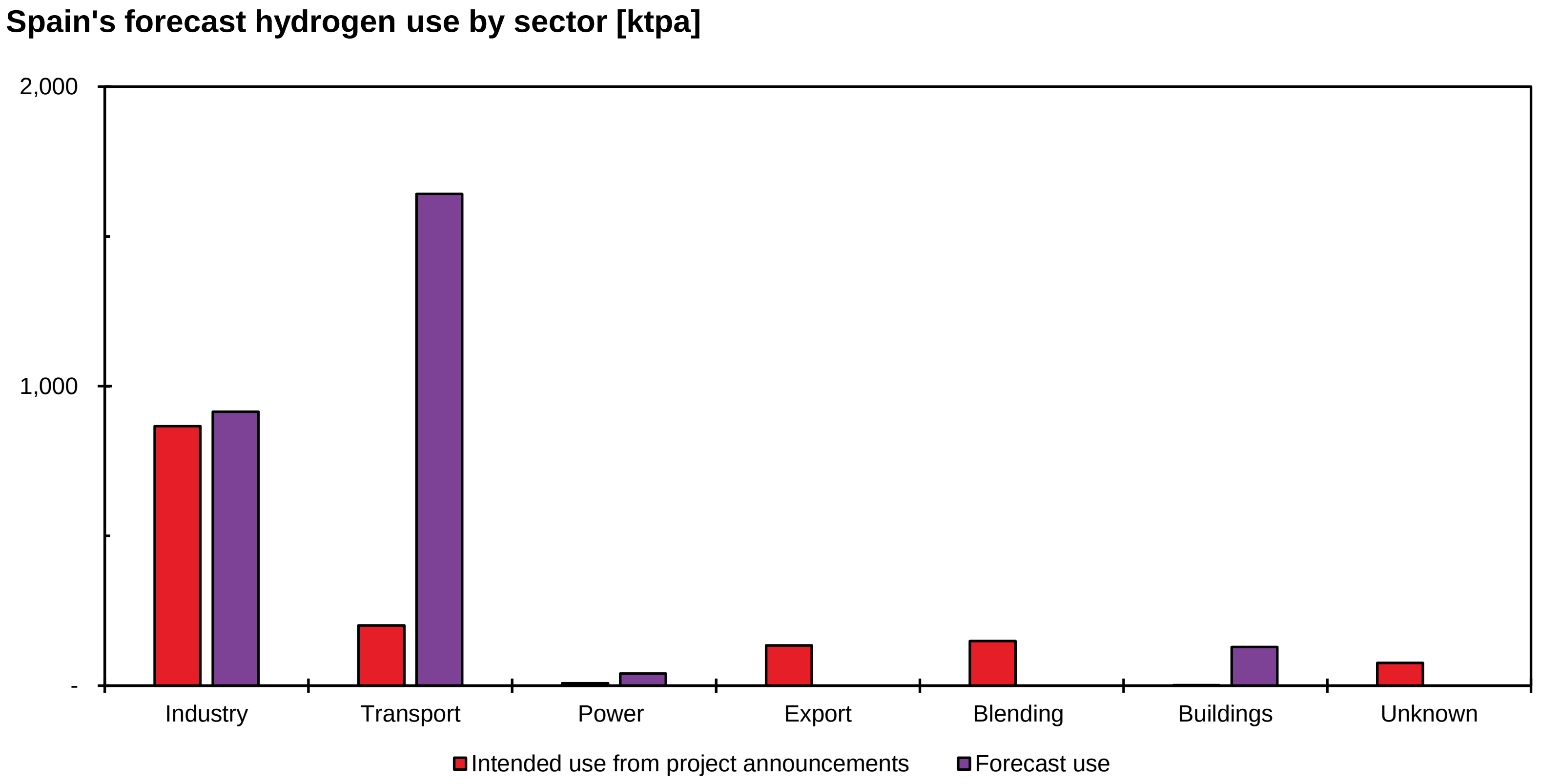
4.4. Spain
Priority Market Assessment

Hydrogen use

Spain's hydrogen strategy primarily targets industry, transport, and power, as reflected within their sector impact targets[1]. This is broadly consistent with the demand forecast and the intended use by project, presented opposite. In both cases, industry and transport are the primary use cases.

Use within the industrial sector will likely centre around displacing current fossil fuel-based hydrogen consumption; Spanish industry currently uses 500 ktpa of grey hydrogen. This is predominately within oil refining, steel production, and derivative production, all of which are relatively mature and established sectors within the Spanish market. However, this may present opportunities to support the transition of grey hydrogen facilities to blue hydrogen through carbon capture and storage.

Use within the transport sector primarily focuses on use in road vehicles (such as buses and good transport), trains, and heavy machinery / equipment. Refuelling infrastructure will be critical to achieving this ambition, with an estimated 100-150 refuelling stations being required by 2030[1]. This will require substantial deployment of 13-20 stations per annum to scale up from the 11 currently operational[2]. This is an emerging part of the Spanish market, while Scotland benefits from strong experience in the area meaning there is potential opportunity for Scotland to export capability in this area to the Spanish market. Logan Energy, a Scottish company included in the case study section of this export, has experience exporting products, solutions, and services in this area.



Spain's forecast hydrogen use – based on announcements from projects (red) and an assessment by Arup (purple).

Source: Arup assessment of hydrogen demand (purple) and project data from BloombergNEF (red).

1. The Spanish Hydrogen Strategy – WFW
2. Hydrogen Stations Spain. Map and List Updated (glpautogas.info)

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4.4. Spain
Priority Market Assessment

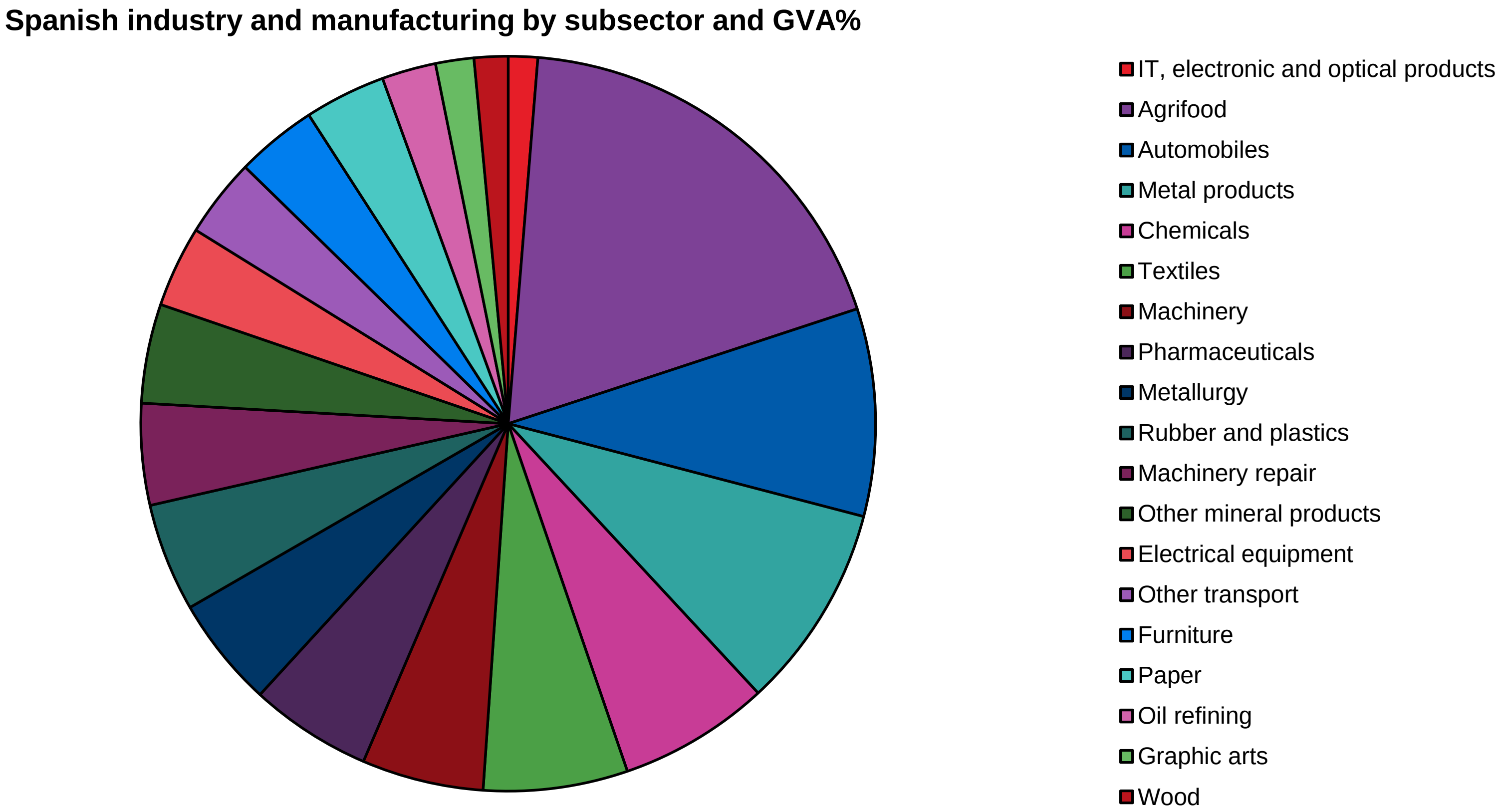
Wider economy

The Spanish economy is one of the largest and most diversified within Europe, ranking 14th globally and 5th in Europe with a GDP of $1.28tn in 2020[1]. A key aspect of Spain's economy is their industrial and manufacturing sector.

As presented opposite, the Spanish industrial and manufacturing sector is diversly spread, with the largest outputs centring around agri-foods and the automotive industry. However, it is not particularly suited for rapid scale up of the hydrogen sector.

Process equipment and electrical equipment are crucial products across the hydrogen supply chain, and do not make up a significant aspect of Spain's manufacturing output.

This represents a potential gap within the market , which plays to Scotland's manufacturing strengths.



Spain's industrial and manufacturing sector

Source: An overview of Spain's manufacturing industry (caixabankresearch.com)

1. The Biggest Industries In Spain - WorldAtlas

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4.4. Spain
Adjacent Market

Morocco

Morocco was a top scoring market within the Market Prioritisation Assessment. Due to its close proximity to Spain, it was decided that it would be included as an adjacent market of interest.

Morocco has ambitious plans to be a key player within the green hydrogen sector. The market published a national hydrogen strategy in 2021 detailing a roadmap for growing the sector based on three pillars[1]. These pillars are:

- Technology: cost reduction through R&D, innovation, and scale up.
- Investment: support the creation of industrial clusters and ensure appropriate financing.
- Market and demand: create a favourable export market through tax incentives and port infrastructure, along with developing a local market.

The strategy sets out the following timeline for developing the sector[2].

- 2020-2030: local use as a raw material and export to targeted countries.
- 2030-2040: production cost reduction and local use within the electricity sector.
- 2040-2050: improved business case at the world level and expanding local use.

Morocco's strategy centres on green hydrogen production, utilising its access to good natural resources for solar and wind. This is supported by the assessment that found 100% of the c. 1,300 ktpa of production will be via electrolysers.

Morocco's local use of hydrogen will centre around the industrial sector, primarily in fertiliser production. Their strategy aims to produce green ammonia, which is currently imported, for fertiliser production[2,3]. This is supported by the assessment, which found the industrial sector to have the greatest share of demand. Transport was also forecast to be significant use sector; however, this does not feature within Morocco's strategy.

Opportunities for Scotland will centre around green hydrogen and ammonia production. The market prioritisation assessment found that Morocco had relatively low in-market capability, suggesting that there would be limited competition. However, a more detailed assessment will be needed to establish exact opportunities, in-market competition and barriers to entry.

4 TWh

2030 local market

10 TWh

2030 export market

1. National Hydrogen Strategy – Policies – IEA
2. Morocco | Green Hydrogen Organisation (gh2.org)
3. Morocco aims to become key player in green hydrogen (techxplore.com)

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4.4. Spain
Key Findings

A summary of the key strengths, weaknesses, opportunities and threats for Scotland to export hydrogen supply chain capability to Spain are set out below.

Strengths	Weaknesses	Opportunities	Threats
• Scotland has experience manufacturing crucial subcomponents for electrolyser OEMs, with companies such as Langfields currently doing so. • Scotland's experience in the execution of oil and gas projects, particularly mechanical installation, electrical installation, and commissioning. • The Oil & Gas industry has many transferable skills to support carbon capture and storage projects. • Scotland is geographically and politically close to the Spanish market, increasing the ease of entry.	• Slow judicial system with a lack of predictability on decisions. • High regulatory burden. • Lack of research and development incentives. • Some political uncertainty at national and regional levels.	• Supply of subcomponents to in-market electrolyser manufacturing. • Supply of products, solutions, and services relating to hydrogen refuelling infrastructure. • Supply of solutions, such as mechanical installation, electrical installation, and commissioning during project execution. • Supply of services and solutions related to hydrogen distribution via pipelines. • Supply of cross-cutting products, such as process and electrical equipment, across the supply chain. • Support conversion of existing grey hydrogen production to blue via CCS	• Other markets, such as China, can likely provide products at a lower cost. • Electrolyser OEMs usually have trusted suppliers, increasing the difficulty for new suppliers to enter the market. • Spain has relatively strong in-market capability, compared to other priority markets, meaning the market is likely to be competitive.

Section 4.5.

Australia

4.5. Australia
Priority Market Assessment

Hydrogen outlook

The Australian hydrogen market is a growing sector that aims to produce and use hydrogen as a low carbon and versatile energy source. The Australian government developed a National Hydrogen Strategy in 2019, which sets out a vision for a low carbon, innovative, safe and competitive hydrogen industry that benefits all Australians[1]. The strategy outlines seven areas of action for the development of the hydrogen sector, including: national coordination, developing production capacity, responsive regulation, international engagement, innovation and R&D, skills and workforce development, and community confidence.

While there is no production target specified, the strategy identifies potential scenarios for the growth of the hydrogen market in Australia by 2030 and 2050. According to the strategy's pre-feasibility study, Australia could export 200 ktpa - 1 Mtpa of green hydrogen by 2030 under scenarios of global demand growth and policy support[2]. The strategy also recognises the importance of domestic demand for hydrogen in Australia. Under a scenario of domestic demand growth driven by decarbonisation of existing industrial uses of hydrogen (such as fertiliser production), Australia could use up to 100 - 300 ktpa green hydrogen by 2030.

The strategy also acknowledges the potential for blue or grey hydrogen production in Australia. However, these sources are not considered as sustainable or competitive as green hydrogen production in the long term.

Some of the key opportunities for hydrogen in Australia include leveraging Australia's abundant renewable energy resources (such as solar PV) for green hydrogen production; benefiting from Australia's existing infrastructure assets (such as gas networks) for blue-green production; accessing global markets (such as Asia-Pacific) for export demand; creating new jobs (such as engineering) in the emerging sector; and contributing to environmental goals (such as climate change mitigation).

A key element of the Australian Strategy is development of seven hubs across the country enabling co-location of production and users to reduce costs. Regional Hydrogen Hub funding has been announced for projects in[3]:

- the Pilbara and Kwinana in Western Australia
- the Hunter in NSW
- Bell Bay in Tasmania
- Gladstone in Queensland
- Port Bonython in South Australia.

A $2bn Hydrogen Headstart Programme is open for Expressions of Interest to provide revenue support to large scale renewable hydrogen projects. The government is also working with industry to create a Guarantee of Origin Scheme[3].

1 Mtpa

demand by 2030 (up to)

$2bn

available in public funding

1. Australia's National Hydrogen Strategy – DCCEEW
2. Government Hydrogen Policies for Australia | AHC (h2council.com.au)

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4.5. Australia
Priority Market Assessment

Hydrogen Production

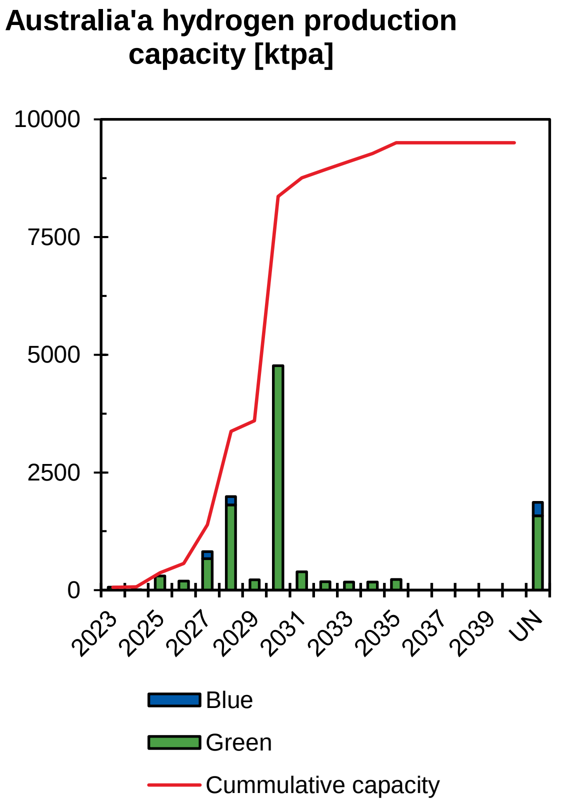
The Australian market will target a mix of electrolysis and thermochemical production; however, this will be largely dominated by green hydrogen production. This means that this the production segment of the supply chain will be dominated by any products, solutions, and services that relate to green hydrogen. Australia has a significant advantage with the land mass available for hydrogen production – estimated at 262,000 sq km in the National Hydrogen Strategy[1].

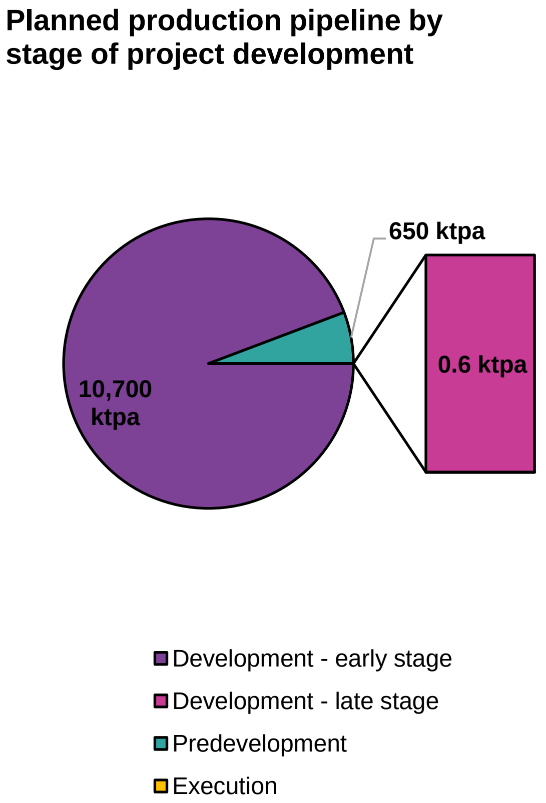
Australia has a very strong pipeline of over 100 production projects, with 80GW of electrolyser capacity forecast to be commissioned by 2030 and 90GW by 2050[2]. This is a significant scale of project pipeline compared with other priority markets. However, most projects are still at early planning stages and only three have reached financial completion.

Therefore, in the near-term, this segment of the market will mostly require services. It will not be until the latter half of the decade, where a significant demand for products and solutions could be anticipated. Based on the pipeline for Australia, there will likely be significant requirement for equipment, EPC skills and hydrogen offtakers towards the late 2020s to achieve development of projects.

Several demonstration projects are currently operational, including seven hydrogen refuelling stations and six hydrogen gas blending projects[3]. Multi-use hubs underway include the Clean Energy Innovation Hub in Western Australia, Hydrogen Park South Australia, Swinburne University of Technology Hydrogen Hub and Toyota Ecopark.

Australia are also investing in building their hydrogen supply chain. For example, Fortescue Future Industries have invested $3bn in their Gladstone electrolyser manufacturing plant, one of the largest hydrogen electrolyser manufacturing plants in the world.





Spain's hydrogen production capacity, including annual additions by technology, cumulative capacity, and the government's 2030 production target (left) and by stage of project development (right).

Source: BloombergNEF and Arup assessment.

1. Australia's National Hydrogen Strategy – DCCEEW
2. BNEF Hydrogen Market Outlook

4.5. Australia
Priority Market Assessment

Hydrogen Use

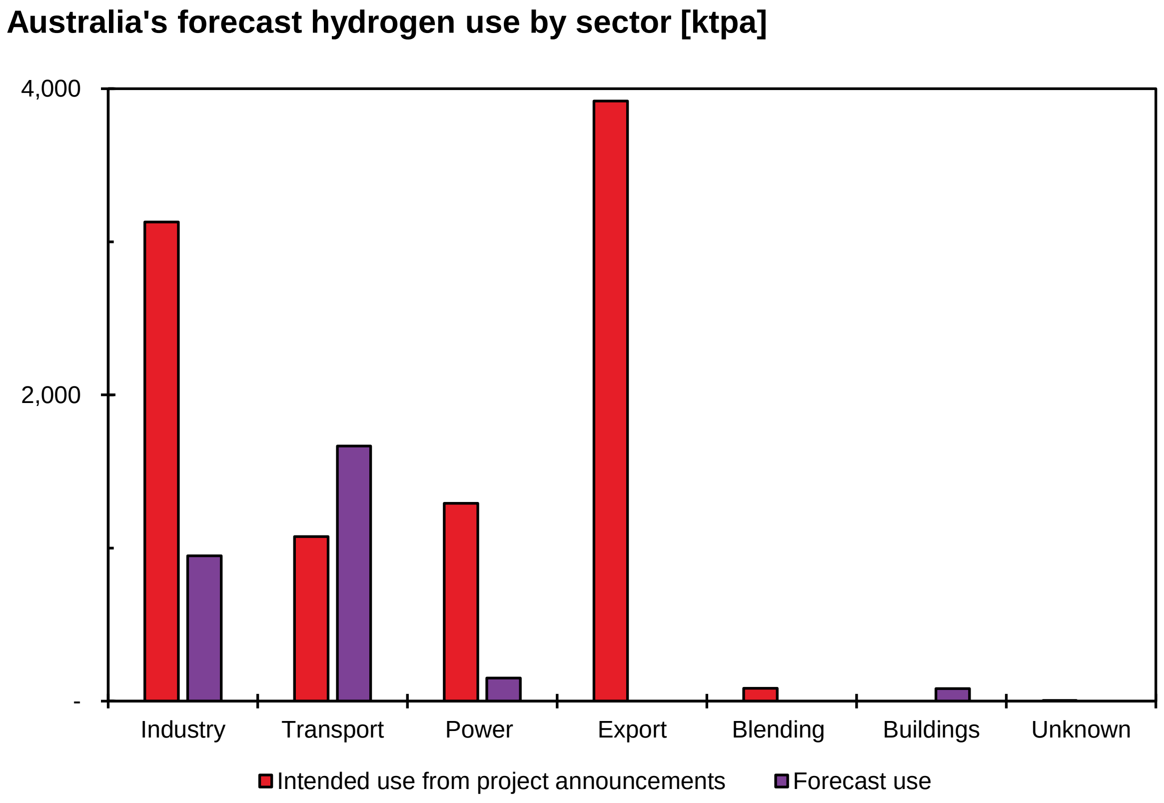
Australia's hydrogen strategy primarily targets industry, transport, and power, as reflected within their National Hydrogen Strategy. This is broadly consistent with the demand forecast and the intended use by project, presented opposite. In both cases, industry and transport are the primary use cases.

The biggest use for hydrogen in Australia currently is using hydrogen as a chemical feedstock in areas such as ammonia production. The Hydrogen Strategy views ammonia production as an opportunity to jump start the hydrogen economy and progress has been made developing hydrogen projects for this purpose. As the biggest iron ore producer globally, feasibility studies into low emissions iron ore processing are also underway.

In the transport sector, several hydrogen refuelling stations are being trialled for buses, fleets and freight. The Victoria, NSW and Queensland governments are collaborating on hydrogen highways which will deliver the first hydrogen refuelling network by 2025[1].

Hydrogen blending is also being considered, with small amounts of hydrogen blending being trialled in Western Australia's gas distribution network alongside other small demonstration projects.

Future export opportunities are being investigated, particularly ammonia in shipping, and Australia is proactively developing supply chains with several countries, including Japan and Korea which are key markets for export. The Australian and Victorian Governments have partnered with Japanese industry through the Hydrogen Energy Supply Chain project[1]. Australia's geology is also highly suitable for the long-term storage of hydrogen in salt caverns to enable large scale export.



Australia's forecast hydrogen use – based on announcements from projects (red) and an assessment by Arup (purple).

Source: Arup assessment of hydrogen demand (purple) and project data from BloombergNEF (red).

1. Australia's National Hydrogen Strategy – DCCEEW

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4.5. Australia
Priority Market Assessment

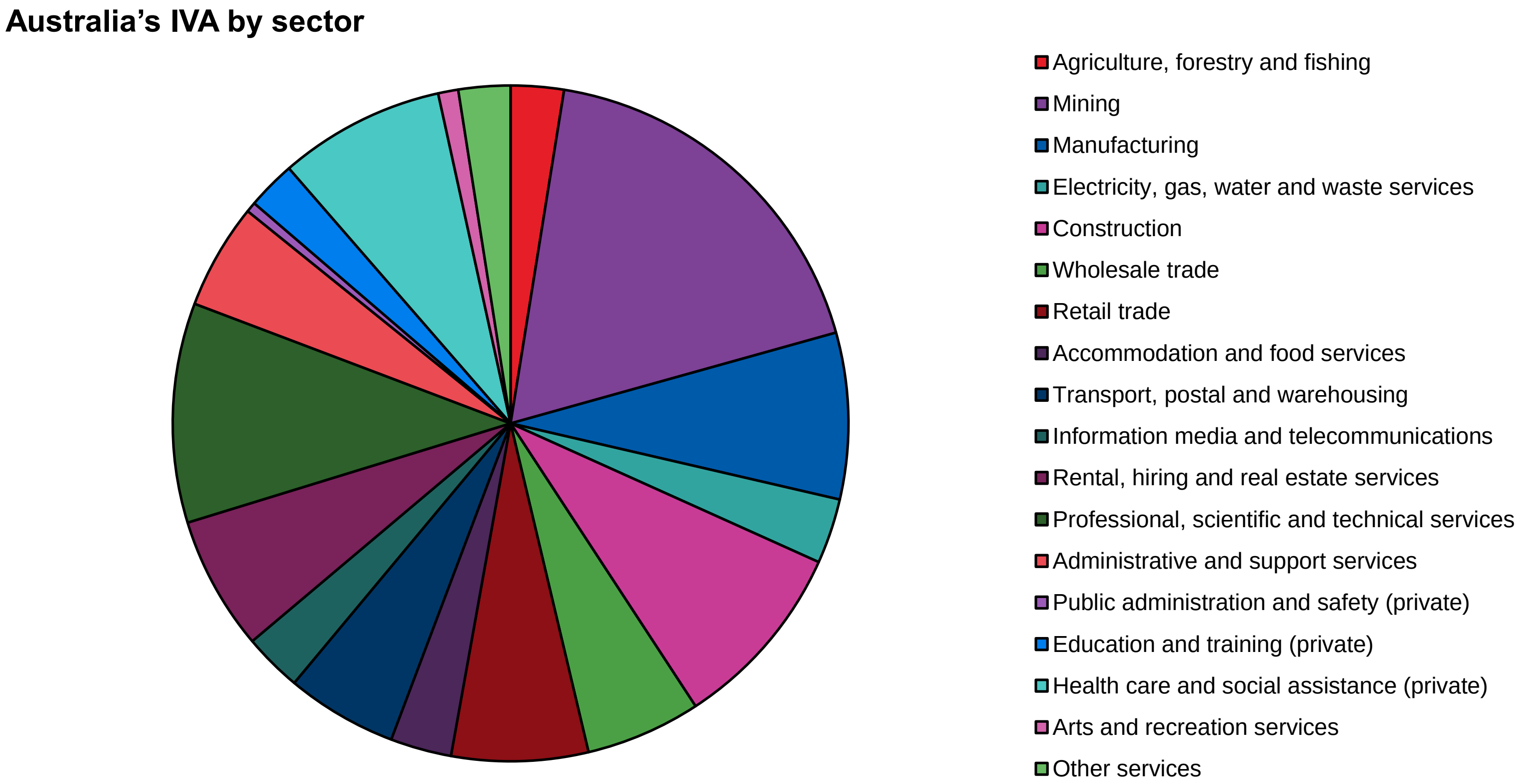
Wider Economy

Australia has had a stable and resilient economy, with a business-friendly low tariff and regulatory environment. Through the late 20th century, Australia has started moving from a farming and mining based economy to a service and manufacturing based economy. Australia participates on the global stage and is developing strong connections to the Asia-Pacific region.

Australia's growing industries include renewable energy, advanced manufacturing, technology and digital, agritech, health, and infrastructure.

Australia has considerable mineral resources including iron ore, copper, gold and uranium. As the world's largest iron ore producer, exporting almost 900 tonnes annually, Australia is looking to reduce emissions in the iron and steelmaking industries[1]. Some of Australia's mining companies have begun investigating this opportunity.

Australia also has large fossil fuel reserves of coal and natural gas and is one of the largest coal and LNG exporters. Coal has traditionally been used to generate electricity via thermal power stations resulting in a high carbon intensity. In 2022, fossil fuels made up 85% of Australia's energy mix. However, the Australian government has a Net Zero plan with a goal of reaching net zero by 2050. As a largely sunny and dry continent, Australia's solar and wind industries are growing, but to date remain a relatively small proportion of the energy mix (c. 10%). Abundant land and high-capacity factor renewables provide good potential for cost competitive green hydrogen.



Australia's Industry Value Added by sector for 2022

Source: Australian Industry, 2021-22 financial year | Australian Bureau of Statistics (abs.gov.au)

1. Australia's National Hydrogen Strategy – DCCEEW

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4.5. Australia
Key Findings

A summary of the key strengths, weaknesses, opportunities and threats for Scotland to export hydrogen supply chain capability to Australia are set out below.

Strengths	Weaknesses	Opportunities	Threats
• Secure economy, open to international business with a low tax and regulatory environment. • Supportive government and hydrogen strategy in place (although no specific targets in place), along with financial backing. • Strong pipeline of hydrogen projects, expected to be one of the largest hydrogen producers globally. Several refuelling and blending demonstration projects already underway. • Good political alignment, with trade agreements in place.	• Australia is relatively advanced in hydrogen development globally (although still at early stage). They are already developing the supply chain (e.g. Gladstone electrolyser manufacturing plant) and may be ahead of Scotland in terms of supply chain development.	• Australia's planned use cases could align well with Scotland's research and experience, through early hydrogen buses deployed in Aberdeen to the H100 trial of hydrogen in the gas network in Fife. • Good opportunity to provide services to the early hydrogen industry. The UK is Australia's second-largest source of services imports and foreign investment. • Australia still needs to transition from a fossil-fuel based energy system, similar to Scotland's transition from coal, oil & gas. Potential to share experience and learnings from transitioning to renewables and hydrogen. • Interest in hydrogen hubs could align with Scotland's capability and ambition. • Open to international business investment – Aberdeen-based Xodus Group is already developing the MercurHy electrolysis project in Australia.	• Distance from UK, Australia increasingly has ready access to Asian and other low-cost producers with which Scotland would need to compete.

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Section 5

Findings & Next Steps

5. Findings & Next Steps

This report highlights the role that Scottish companies could play in the global hydrogen skills and services market. It provides a high-level overview of the current market in Scotland, including the key products, solutions, and services where Scotland has an advantage. The ambition and capability to deliver hydrogen projects has been assessed based on publicly available information for over 170 countries. A multi-criteria analysis has been used to score the countries to identify those where Scottish companies may have the highest opportunity to export to. This was based on a scoring metric and weighting that was agreed with the project steering group. Five countries where targeted for a more in-depth review due to their high scores from the analysis. They are:

- Egypt
- Chile
- India
- Spain, and
- Australia.

Egypt

Egypt were the highest scoring nation from the analysis. They have a combination of significant ambition, limited internal capability and strong alignment with Scotland. Their planned target of 1.4GW of green hydrogen by 2030 makes them a good target for Scottish companies. However, it is likely that local partners would be required in Egypt so engagement is important to secure those links.

Chile

Chile scored very highly in the analysis due to high ambition and strong alignment. There is greater in country capability in Chile there are still significant gaps that Scottish companies could fill. Chile's huge targets and export potential make it appealing but there remain several challenges and risks associated with the development of hydrogen in Chile including economic uncertainty and water scarcity.

India

India had the highest ambition score due to their high, policy backed targets. As it stands, they also have limited capability but it is growing rapidly. The Indian government is focused on ensuring local content within the delivery of hydrogen projects and therefore, it might be a challenge for Scottish companies to make market entry. Early engagement with the Indian sector will be important to allow Scottish companies the opportunity to work on their projects.

Spain

Spain, with its close links to Morocco and geographical proximity, scores highly across ambition and alignment with a lower capability score. There is already a significant hydrogen adjacent industry in Spain, which makes the likelihood that local content could be used in Spanish projects high. However, there remain key market gaps supporting system integration where Scottish companies could play a role, and in some cases they already are.

Australia

Similar to Spain, Australia scores very highly in ambition and alignment but has a lower capability score. Australia is advanced in developing its hydrogen sector in comparison to many other nations. However, the scale of the targets and economic opportunity mean that possibilities remain for Scottish companies. One of the primary issues with entry into the Australian market is simply the distance as it is likely offices or manufacturing facilities would be better established in-country rather than exporting from Scotland.

Next Steps

Engagement

Playing a role in the development of the hydrogen sector in any of these markets will require early engagement with local partners both public and private. This will be vital to create a foothold in markets with such high ambition.

Expanded Analysis

This report presents a high-level analysis of publicly available information on 175 nations. A more focused and detailed study on some of the top scoring nations would likely reveal other good opportunities for Scottish involvement.

Scottish Capability

A broad analysis of Scottish capability across the hydrogen supply chain would better identify Scottish strengths for export. This could then tease out other nations with clear alignment.

Appendix A

Market Prioritisation & Assessment | Assumptions & Further Details

ARUP

Appendix A
Market Prioritisation & Assessment | Assumptions & Further Details

Section	Topic	Commentary / Assumptions
Market Prioritisation	Production Forecast	• Forecast was based on the announced pipeline of projects using data compiled from BloombergNEF.
Market Prioritisation	Demand Forecast	• Forecast was based on global emissions by sector for 2020 ($Emissions_{global}$); global energy use by sector for 2020 ($Energy_{global}$); emissions by country and sector for 2020 ($Emissions_{market}$); and predictions for hydrogen penetration by 2050 by sector from literature (Penetration). • These terms are related to hydrogen demand using the below formula: $Demand = (\frac{Emissions_{global}}{Energy_{global}})^{-1} \times Emissions_{market} \times Penetration$ • Demand was assessed for Industry, Transport, Power, and Buildings for each of the markets assessed. • It was assumed that carbon intensity (i.e., ratio of energy to emissions) by sector is uniform globally (e.g., the carbon intensity for industry is the same in the USA and UAE). • It was assumed that hydrogen penetration into each of the sectors will be uniform globally. • Emission data was sourced from Our World in Data; energy data from the International Energy Agency; hydrogen penetration from BloombergNEF and the Royal Society of Chemistry.
Market Prioritisation	Hydrogen Adjacent Capability	• HACI was based on energy data for 2023 compiled from the Energy Institute's Statistical Review of Energy. • It was assumed that oil and gas production, biofuel production, and refinery capacity are direct indicators of adjacent capability.
Market Prioritisation	Market Alignment Index	• MAI was based on Arup's qualitative ratings of Scotland's strengths and the results of the production and demand forecast.
Priority Market Assessment	Hydrogen Production	• Reported production was based on the production forecast and uses data from BloombergNEF.
	Hydrogen Use	• Reported use was based on the demand forecast and intended offtake from project announcements as reported by BloombergNEF.