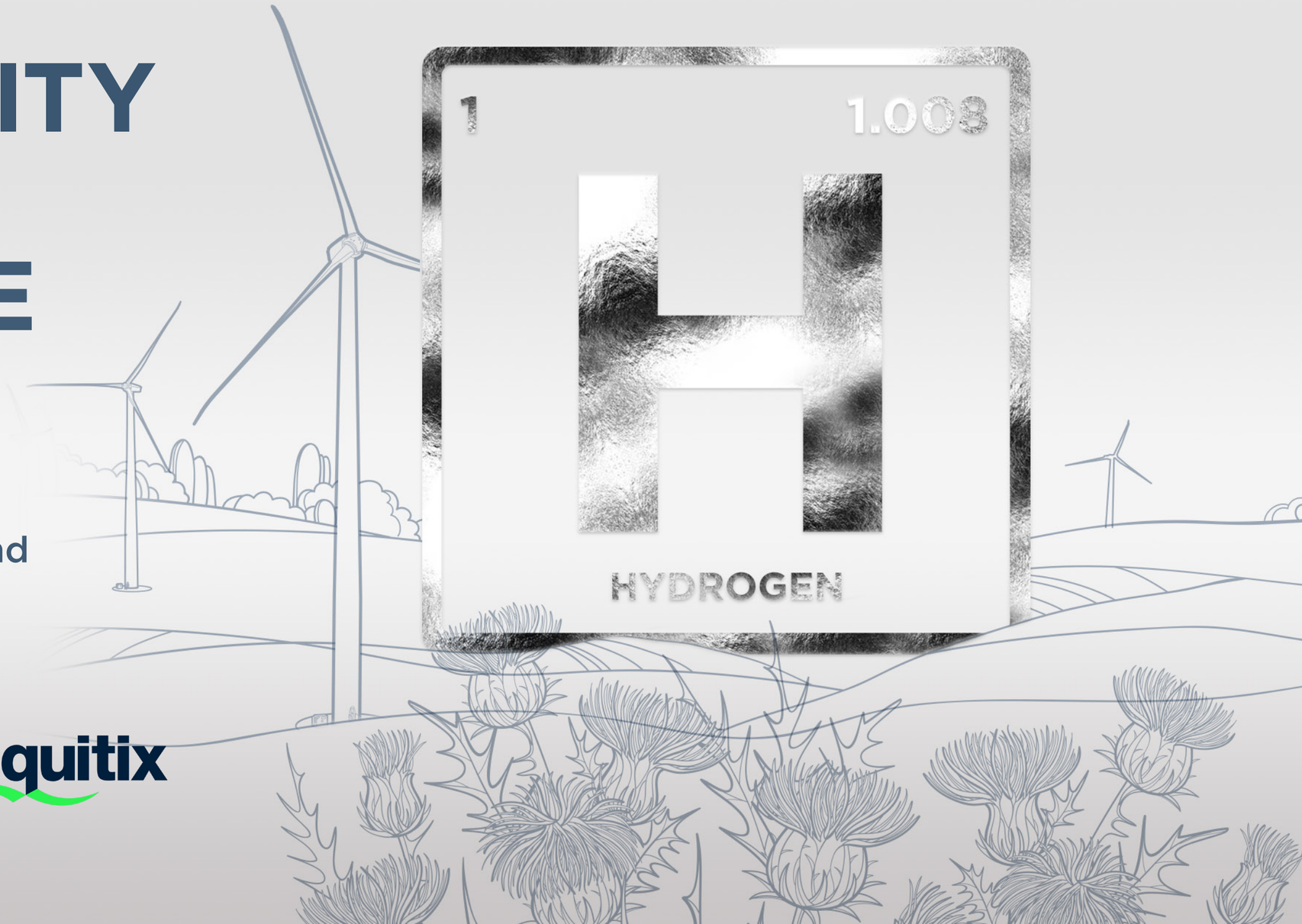
THE OPPORTUNITY AND THE CHALLENGE

Turning ambition into delivery:
building an investable hydrogen value chain in Scotland



ADDLESHAW GODDARD

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MORE IMAGINATION MORE IMPACT

FOREWORD

Against a backdrop of concerns over energy security, extreme price volatility and the climate crisis the potential role of low-carbon hydrogen is rapidly moving up the agenda.

Scotland's abundant natural resources put it in a strong position in the global race to exploit the potential. Replacing fossil fuels with hydrogen across industries and in hard-to-decarbonise sectors such as transport could turbo-charge the nation's progress towards Net Zero. Tens of thousands of new jobs could be created at a time when North Sea production is winding down.

Scotland has recently set ambitious targets which would see it become a world-leader in this emerging sector. However, significant hurdles will need to be overcome across the value chain to establish the business case for low-carbon hydrogen.

While the technology for production is already in use, deploying it at scale presents many challenges. That production will also need to be closely aligned with demand, and new infrastructure and storage facilities will be required alongside integration with existing energy networks.

Although in the long-term the cost of low-carbon hydrogen is expected to fall dramatically, it is likely to remain more expensive than fossil fuels for years ahead and effective support mechanisms are needed to bridge the gap.

Investors also need much more certainty on the business models which are still evolving, alongside policy and regulation across areas including safety and quality.

The different pieces of the hydrogen puzzle are starting to take shape in Scotland, but bold and decisive actions from government, industry and funders are now needed to bring the picture together.

For this report we wanted to find out what those on the frontline of the emerging hydrogen economy in Scotland – from potential producers and users to investors and policymakers – see as some of the key issues and we're grateful to the insight provided by the individuals who contributed.

We hope it will make a valuable contribution to the many conversations now taking place around the exciting opportunities a vibrant Scottish hydrogen economy present.

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THE OPPORTUNITY AND THE CHALLENGE

THE CURRENT POSITION

- More than 60 demonstration projects underway in Scotland across sectors including industry and transport
- Scottish and UK governments have signalled intent to dramatically scale-up both the production and use of low-carbon hydrogen
- Capital funding of £100m in place to accelerate hydrogen economy in Scotland.

THE AMBITION

- 5GW of low-carbon hydrogen production in Scotland by 2030 and 25GW by 2045 driven by growth in renewable energy capacity
- £25bn economic prize with up to 300,000 new or secured jobs across all skill levels
- Major new export industry – EU alone has target to import 10m tonnes of hydrogen by 2030
- Opportunities to decarbonise across industry, transport & heating

THE CHALLENGES TO OVERCOME

- Clarity on policy and strategy
- Stimulating demand and aligning with production
- Attracting investment into a new asset class
- Visibility on financial support for projects
- Overcoming power grid and market issues
- Streamlining planning and consents
- Securing skills and supply chain resources

> **Hydrogen may be Scotland's greatest industrial opportunity since oil and gas.**

Michael Matheson MSP,
Former Scottish Cabinet Secretary for Net Zero, Energy and Transport

> **If we do this right, we will not only deliver Net Zero but also deliver some massive benefits for Scotland.**

Nigel Holmes, CEO, Scottish Hydrogen and Fuel Cell Association

> **Scotland has a key role to play in the development of a UK hydrogen economy, with potential to produce industrial-scale quantities of hydrogen from offshore and onshore wind resources, wave and tidal power, as well as CCUS, supported by a strong company base and valuable skills and assets in oil and gas, offshore wind and energy systems.**

Graham Stuart, UK Minister for Energy Security and Net Zero

> **There are already a great many hydrogen projects underway both in Scotland and the rest of the UK, moving towards building the evidence base and deployment; we need to capture this momentum and work towards scaling up and commercialising the industry.**

Scottish Renewables

> **If the policy gaps are addressed, and the UK Government jumps on the opportunities in Scotland, we could be a major exporter of clean energy with thriving clusters and local economies.**

Pete Wishart MP,
Scottish Affairs Committee Chair

EXECUTIVE SUMMARY

Hydrogen has been used across industry for many years, but Russia's invasion of Ukraine and the increasingly urgent focus on the climate crisis has accelerated the push to exploit lower carbon sources.

In the UK, governments at both Holyrood and Westminster have recently published a raft of policy documents setting out how they intend to make the most of the opportunities for blue and green hydrogen to accelerate the journey to Net Zero.

The Scottish Government wants to see hydrogen provide the equivalent of a sixth of the nation's energy needs by 2030, and for production capacity to then increase fivefold by 2045.

That would represent a huge leap from where we are today and would be dependent on Scotland harnessing a number of advantages it has in the global race to be a leading player in the emerging hydrogen sector.

Seizing economic opportunities

The most significant of those is its renewable resource. ScotWind – the largest offshore wind leasing round to date in the world - alone could deliver as much as 27.6GW of new generating capacity, more than 10 times what is currently in Scottish waters.

With highly ambitious targets to grow onshore wind alongside expansion of hydro, solar and marine renewables, Scotland is set to be an increasingly important green energy powerhouse in the decades ahead.

Abundant supplies of water, essential for green hydrogen production but increasingly scarce in many parts of the world, also put the nation in a strong position compared to other countries.

Although much of the focus is around the benefits in terms of energy security and decarbonisation, there could also be considerable economic rewards for Scotland from a thriving hydrogen economy.

With demand for hydrogen – particularly green hydrogen – forecast to grow dramatically across Europe, Scotland's excess energy could be used to develop a major new export market.

The infrastructure, supply chain and skills developed for the oil and gas industry in Scotland could be repurposed within a new hydrogen sector, supporting many tens of thousands of jobs.

If long-term hydrogen prices fall as forecasts suggest, Scotland's industrial base could slash its energy and feedstock costs and boost competitiveness.

EXECUTIVE SUMMARY

Turning enthusiasm into action

Scotland is currently at the forefront of work to demonstrate technologies and establish business models for low-carbon hydrogen production and use with many small-scale projects underway.

However, developing a major new industry will now require a step-change in approach. Closely aligning early production with demand - the two sides of the hydrogen equation with distinct issues and commercial drivers - will be critical.

Stimulating domestic demand, alongside a developing export market, will be essential to underpin the emergence of a robust Scottish hydrogen sector. Industry is seen as being the key long-term offtaker, but the response to survey questions asked for this report revealed surprisingly low levels of interest or awareness among Scottish businesses currently.

The decentralised nature of much of Scotland's industrial base also presents challenges given hydrogen is not easily transportable. Radical solutions may need to be considered, such as helping large offtakers to relocate to the best locations for hydrogen production.

The public sector also has a major role to play in creating the early demand through areas such as fleet decarbonisation but significant commercial and risk hurdles first need to be overcome.

Making the investment case stack up

For a robust hydrogen sector to develop, it will need to attract very substantial levels of public and private sector backing. Reaching final investment decisions on projects will require confidence in the long-term cost and revenue models which are yet to be established.

Although hydrogen costs are expected to fall steeply as the benefits of economies of scale and innovation are seen – and the recent rise in gas prices has improved the economic case for green hydrogen in particular - it is likely to remain significantly more expensive than existing fuels for some years to come. Steady progress is being made on developing support schemes, but more detail is needed on how they will work in practice.

Constructive dialogue between Holyrood and Westminster on the development of a hydrogen economy which plays to the strengths of every part of the UK is vital, particularly given key policy areas such as energy and heat are not devolved.

Urgent clarity is needed around the timescales for a decision on the Acorn CCS and Hydrogen projects, seen as critical for decarbonising Scotland's key industrial cluster.

While the UK and Scottish Governments have distinct strategies for hydrogen, a collaborative approach on areas such as regulatory frameworks, market mechanisms and grid connections will be important for strengthening investor confidence across the wider sector.

The creation of a new industry will also require early focus on ensuring Scotland secures the skills and supply chains needed as global competition for resources and equipment intensifies.

THE GLOBAL OPPORTUNITY SCOTLAND'S UNIQUE POSITION

Across the world, countries are looking to exploit the opportunities presented by the emerging hydrogen economy.

The global green hydrogen market is forecast to grow from $1bn in 2021 to $72bn[1] by 2030, a compound annual growth rate of 55% with Europe expected to be the leading player.

Investment activity has almost trebled over the past year alone, with the number of investments in low-carbon hydrogen increasing from 600 to over 1,700, according to research by GlobalData[2]. The growing momentum is expected to accelerate cost reduction across the entire hydrogen value chain.

In recent years Scotland has been playing an increasingly active role in exploring the potential for low-carbon hydrogen with more than 60 pilot and demonstration projects underway, from the world's first hydrogen powered double-deckers being used on the roads of Aberdeen to the first tidal-powered hydrogen electrolyser in Orkney.

The Scottish Government's recently published Hydrogen Action Plan[3] sets out the role low-carbon hydrogen can play in helping achieve the nation's Net Zero targets alongside delivering significant economic benefits.

Achieving production capacity targets of 5GW by 2030 and 25GW by 2045 would reap major economic benefits. The plan estimates that as many as 300,000 jobs could be protected or created with potential Gross Value Added (GVA) impacts of between £5bn and £25bn a year by 2045 depending on the scale of production and exports.

Although governments around the world are developing their own ambitious approaches to support rapid acceleration of hydrogen deployment, Scotland has a number of unique advantages that could enable it to significantly punch above its weight.

Harnessing resources and skills

Scotland is already home to significant renewable energy capacity, and the potential pipeline of projects is set to see that dramatically increase in the years ahead.

The ScotWind[4] offshore wind leasing round could see 27.6GW of new projects operating in Scottish waters with an additional 5.7GW specifically targeting oil and gas decarbonisation.

A further potential 0.5GW will specifically test new technologies including hydrogen and many ScotWind applicants have outlined their intention to incorporate hydrogen production into their developments.

The Scottish Government has also recently set an onshore wind capacity target[5] of at least 20GW by 2030, more than double the current operational capacity, which could also play an important role in driving growth in production capacity.

Water resource also plays a vital role in hydrogen production and Scotland has access to almost 5,000km of coastline along with ground and surface water reserves. At a time when demand on limited potable water resources in other locations is increasing, Scotland is well-placed. The fact that Scotland has a publicly-owned water company is seen as beneficial given the current high-profile problems faced by privatised water companies in the rest of the UK.

Many of the skills and supply chain infrastructure in Scotland's oil and gas sector are also highly transferable to roles in the emerging hydrogen industry. The significant employment benefits starting to be seen from the growth of the offshore wind sector in Scotland point to the potential for hydrogen. According to PwC's latest Green Jobs Monitor[6], growth in the sector means Scotland now has the highest proportion of green jobs in the UK.

THE CHALLENGES IN BUILDING THE INVESTMENT CASE FOR HYDROGEN IN SCOTLAND

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THE NEED FOR A STRATEGIC APPROACH

A recurring theme which emerged from industry stakeholders in compiling this report was how fragmented the sector currently is.

More than 60 hydrogen projects are thought to be underway in Scotland – some of them world-firsts – but they are mostly operating in isolation and are not part of an over-arching strategy.

“A holistic approach which engages right across the board is vital. We need to be thinking more radically about how to create an environment where it is much easier to finance and develop projects,” commented one contributor.

Although there is much enthusiasm around hydrogen, there are also concerns that its potential is being over-hyped and that much time and money will be wasted by governments in pursuing the wrong strategies.

The House of Commons Science and Technology Committee recently concluded that hydrogen was “not a panacea for reaching the Net Zero”[7] but can grow to become “a big niche” fuel in particular sectors and applications.

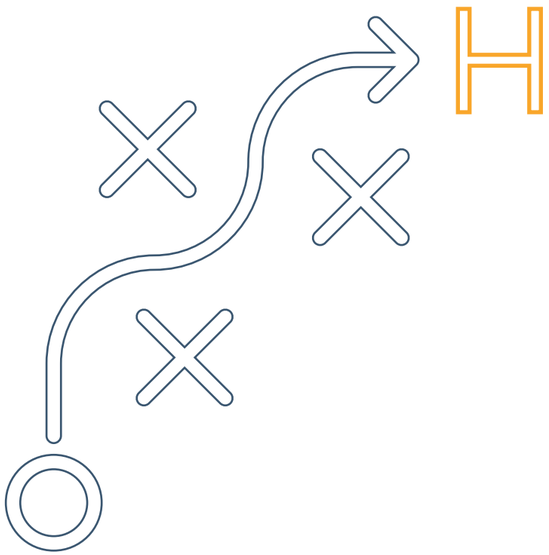
The Hydrogen Action Plan is seen as an important step in establishing the most appropriate strategy for Scotland, but many barriers remain to on-the-ground delivery. An example of the challenges faced was cited in the adoption of hydrogen to help meet stretching targets for decarbonisation of public sector transport fleets.

“The biggest stumbling block is that it is an untested market and local authorities and the supply chain are unable or unwilling to take on the risk needed to get projects off the ground,” said one contributor.

“Local authorities are stuck in the middle right now. The policies and targets are important but there needs to be an understanding of the economics and commercial realities of how these projects need to come together to make progress.”

A facility for co-ordination between the public and the private sector is seen as important to help catalyse the development of green hydrogen within Scotland, particularly given policy responsibilities for hydrogen across production, transport and industry fall across different government departments.

“Having a single point of contact to represent the public sector and liaise with the private sector - and understand its barriers to investment - could be really valuable in improving communication to help the sector develop,” suggested one contributor.



THE CHALLENGES IN BUILDING THE INVESTMENT CASE FOR HYDROGEN IN SCOTLAND

ANSWERING THE 'CHICKEN AND EGG' DEMAND QUESTION

Developing at-scale production of low-carbon hydrogen poses many technical and funding challenges, but establishing where the demand will come from is perhaps the more pressing issue to address.

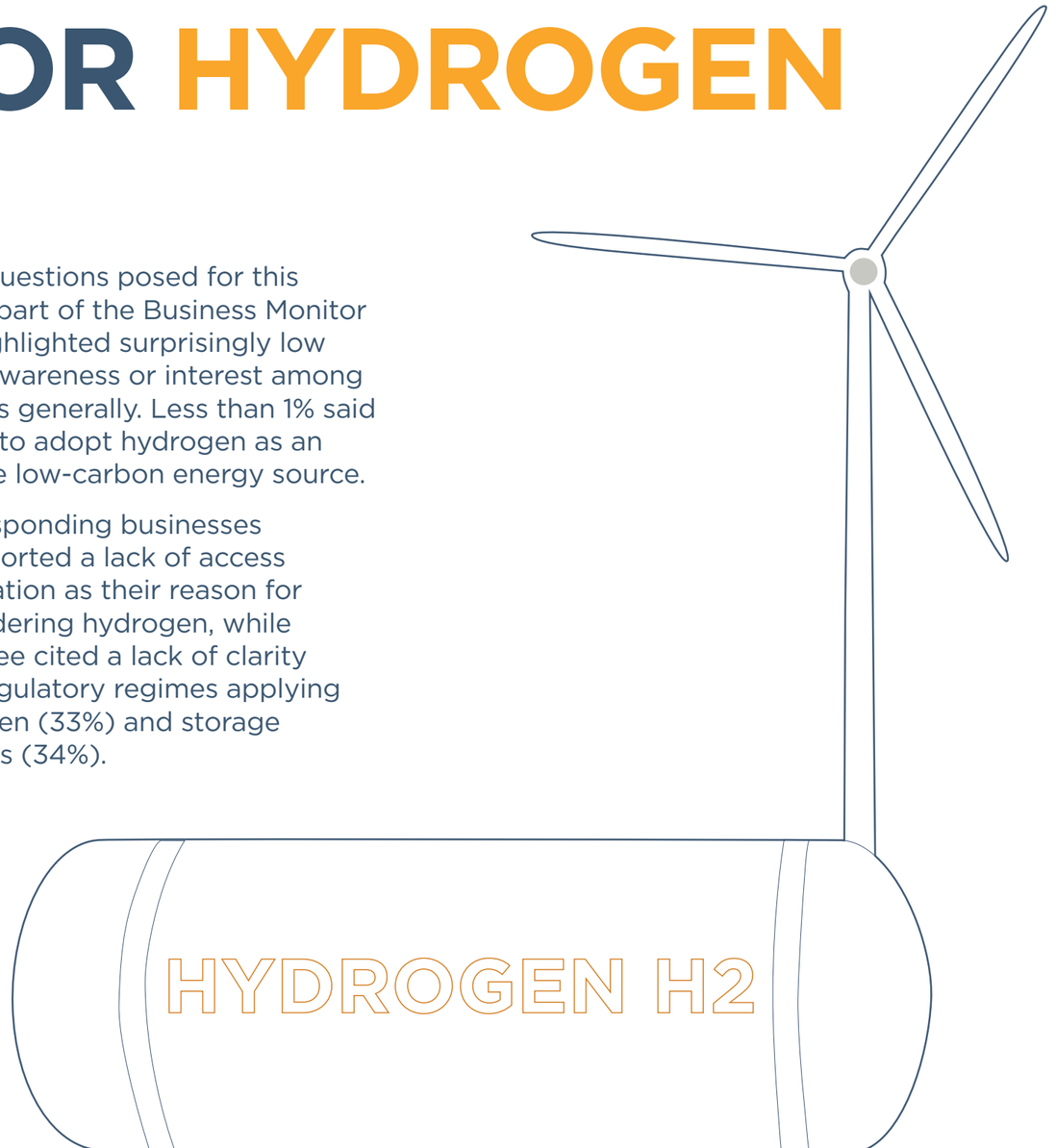
"You could buy an electrolyser, connect it to a Scottish wind turbine and start producing green hydrogen today. But to have a long term viable business model you need to know who will provide the offtake and that's the bit where we've not really seen anything definite forming yet," as one participant pointed out.

The difficulties involved in transporting and storing hydrogen mean that aligning early production with demand is crucial to building a robust domestic hydrogen economy. Industry offtake is likely to be the foundation on which demand from other applications such as transport and heat can be built up.

The UK Government's strategy for hydrogen is focused on a small number of very large industrial clusters. However, the highly distributed nature of Scotland's industrial base means a different approach will be needed north of the Border based on creating pockets of demand to support hydrogen production facilities. Industry may even need to relocate to where the hydrogen is being produced rather than the other way around, a trend which is already being seen elsewhere in Europe.

Although a number of major industrial energy users are considering hydrogen as part of their decarbonisation options, questions posed for this report as part of the Business Monitor survey highlighted surprisingly low levels of awareness or interest among businesses generally. Less than 1% said they plan to adopt hydrogen as an alternative low-carbon energy source.

Half of responding businesses (50%) reported a lack of access to information as their reason for not considering hydrogen, while one in three cited a lack of clarity around regulatory regimes applying to hydrogen (33%) and storage constraints (34%).



THE CHALLENGES IN BUILDING THE INVESTMENT CASE FOR HYDROGEN IN SCOTLAND

ENSURING EFFECTIVE POLICY COLLABORATION

Although Scotland has its own hydrogen strategy distinct from the UK Government's, the fact some of the most important powers for the sector's development are reserved to Westminster is seen as a potential impediment to progress.

In areas such as domestic heat, there is concern that Scotland is unable to drive the progress some believe is needed because Westminster is responsible for heat policy and is yet to take a decision on mandating hydrogen-ready boilers.

Although the recent Scottish Affairs Committee report on Hydrogen and Carbon Capture in Scotland[8] observed that relations between the UK and Scottish governments around the sector's development appear to be good, it also warned "there does not appear to be a sense of urgency in the numerous areas requiring attention before hydrogen can be rolled out".

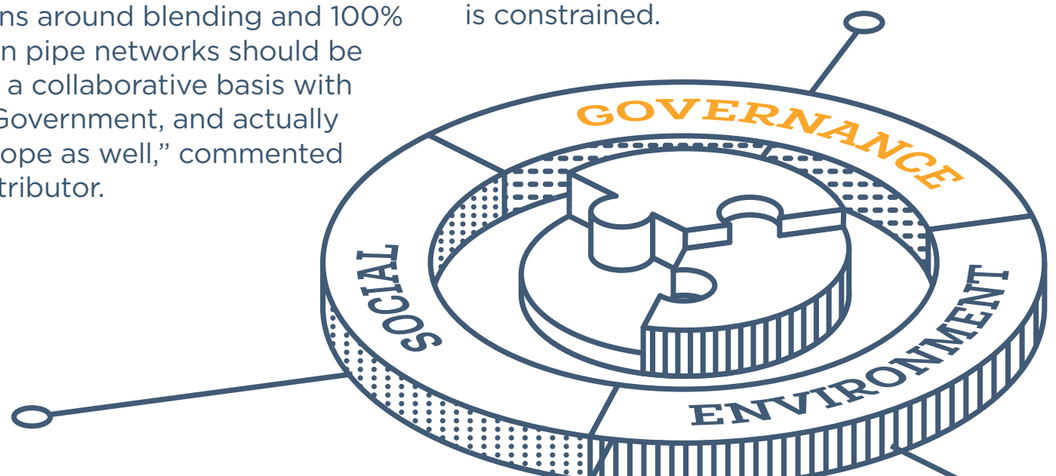
The Acorn project's failure in the UK's initial Track One CCUS cluster sequencing was also seen as a setback. The UK Government has since said Acorn is one of the two best placed projects to be successful in the Track 2 process but there is no certainty around when funding could be awarded. The Hydrogen Champion Report[9] to the UK Government also highlights the need for early clarity on timing and process for the next cluster to "prevent the risk of investment moving away from Scotland".

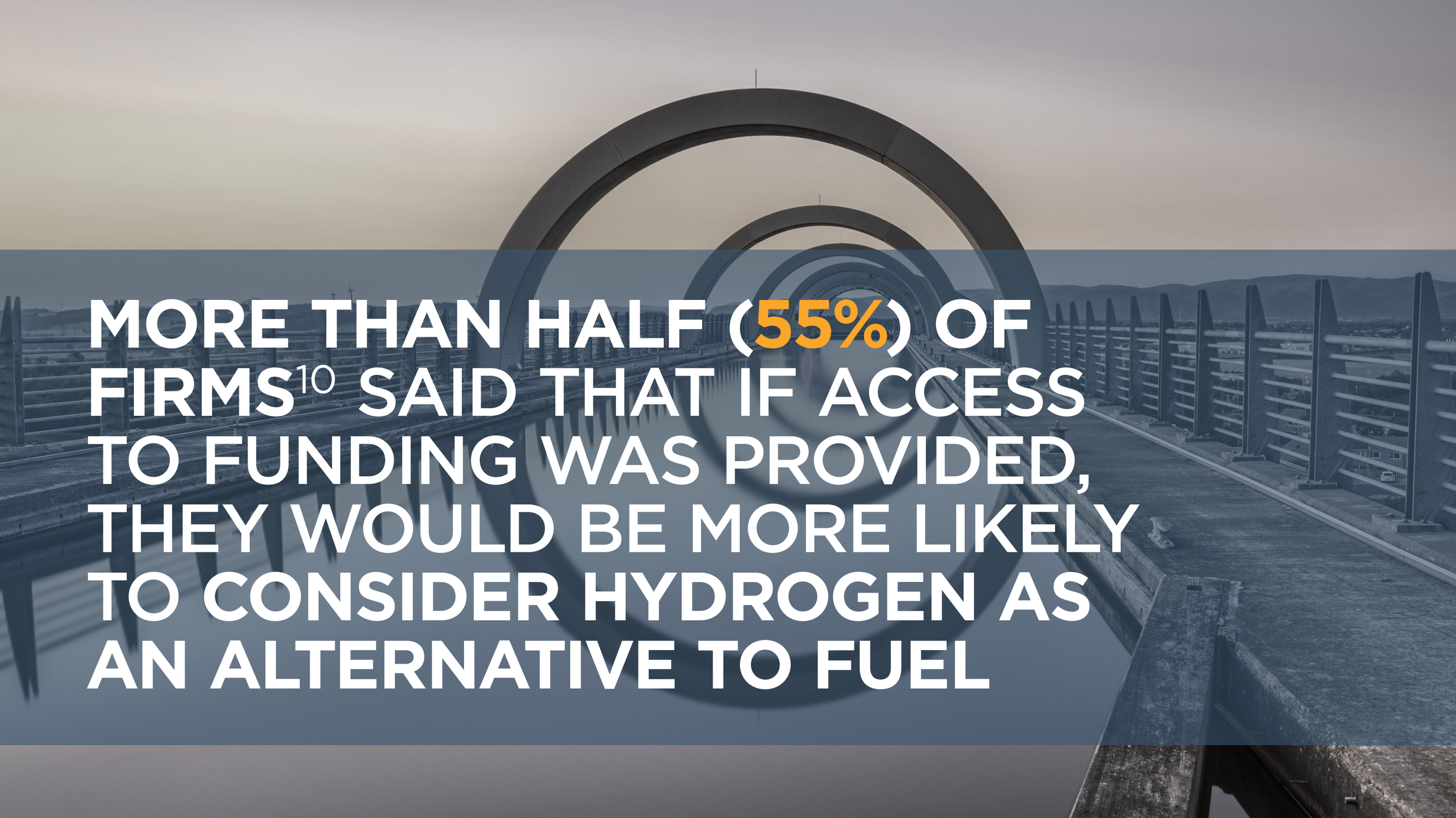
"It's vital to Scottish economic interests to have some clarity around the timetable for the development of Acorn. The longer that is delayed, the more risk there is that it impacts on other decisions about decarbonisation and even around the development of new industry and whether it is in Scotland or not," warned one contributor.

Close co-operation on areas such as regulation and certification is seen as vital to help the sector start to develop.

"Decisions around blending and 100% hydrogen pipe networks should be done on a collaborative basis with the UK Government, and actually with Europe as well," commented one contributor.

Issues such as the current rules under the Renewable Transport Fuel Obligations (RTFO), which aim to support the development of low-carbon transport, were cited by contributors as potential stumbling blocks for hydrogen in Scotland. To produce RTFO-compliant hydrogen demands that a percentage of the fuel supplied must come from a renewable source which also has to be 'additional' – effectively a new generation project or one using power which is constrained.





MORE THAN HALF (55%) OF FIRMS[10] SAID THAT IF ACCESS TO FUNDING WAS PROVIDED, THEY WOULD BE MORE LIKELY TO CONSIDER HYDROGEN AS AN ALTERNATIVE TO FUEL

THE CHALLENGES IN BUILDING THE INVESTMENT CASE FOR HYDROGEN IN SCOTLAND

GAINING CLARITY ON FINANCIAL SUPPORT

Hydrogen costs are widely expected to come down in the long term, with green hydrogen in particular expected to benefits from technology and efficiency improvements which will lower the price of both renewable power and electrolysers.

However, support will be needed to help establish the market while the gap between the cost of hydrogen and fossil fuels narrows.

More than half (55%) of firms responding to the latest Scottish Business Monitor[10] survey said that if access to funding to support transitioning to hydrogen was provided, they would be more likely to consider it as an alternative to fuel.

Governments across the world are looking at the best way to provide that support. In the US, the recently passed Inflation Reduction Act (IRA) means green hydrogen producers could receive up to $3/kg in incentives to set against current production costs of around $6/kg.

Both the Scottish and UK Governments have announced a raft of funding initiatives to help get projects off the ground. The Scottish Government has committed an initial £100m to support its Scottish Action Plan, including a £90m Green Hydrogen Fund which will soon open with a call for proposals for renewable hydrogen projects.

In terms of revenue support, BEIS's low-carbon-hydrogen subsidy scheme – the Hydrogen Business Model (HBM) - will use a contracts-for-difference (CfD) style mechanism similar to that which has helped large renewable energy projects in recent years.

The model aims to bridge the cost gap between low-carbon hydrogen and higher carbon fuels. Progress in developing the HBM has been generally welcomed by the sector, although there are concerns whether a CfD mechanism is the right approach partly due to its benchmarking to power prices set by gas.

Some in the sector believe a regulated asset-based type arrangement would be a better way to secure investment. Others felt the HBM was "unnecessarily complex" for what is needed at this stage of the market's development.

"Do we really need to spend months or even possibly years finessing a business model? For small projects the requirements are probably a bit excessive in terms of the level of detail at a time when we really just want to try and make sure we can move these projects forward as quickly as possible," said one contributor.

More clarity around how the HBM will operate in practice is expected later in 2023 when full contract terms are expected to be published.

Another issue raised is around the extent to which the HBM model incentivises offtakers given there is likely to be capital investment needed to enable switching to using hydrogen.

Although the HBM is taking shape, there are concerns the overall picture for hydrogen support remains "disjointed".

"They have only just closed the consultation on the transportation and storage business models which don't relate at all to the production business models which highlights the real challenge that exists in how policy feeds into delivery," noted one contributor.

THE CHALLENGES IN BUILDING THE INVESTMENT CASE FOR HYDROGEN IN SCOTLAND

ATTRACTING INVESTMENT INTO A NEW ASSET CLASS

The ambitions set out in the Scottish Hydrogen Action plan will require huge levels of investment into production facilities, infrastructure and to support demand-use cases.

High-level commitments from major lenders and investors to support the transition away from fossil-fuels means there is growing interest to invest in hydrogen projects. However, despite a rapidly growing pipeline of potential projects, only 3% of the $700bn investment the Hydrogen Council[11] believes is needed by 2030 to keep global net zero progress on track is currently committed.

Although investment is rising fast from a relatively low base, latest figures show Europe is lagging behind spending in the US and China. Bloomberg New Energy Finance (BNEF) research suggests Europe's low investment levels are mostly due to project delays, as investors waited for more clarity over hydrogen standards and subsidies.

The challenge from an investment perspective is around the building the business cases and models across the hydrogen value chain including production, transport, storage and end-use.

"The confidence in that value chain around renewable hydrogen is just not there yet for investors," said one contributor.

"Private capital has a relatively straightforward perspective on hydrogen in that they need to see a reliable, long-term income stream from any big investment in new assets."

A key issue for hydrogen production projects looking to secure funding is agreeing a contract with an offtaker. However, the long term nature of such agreements – power purchase agreements in the renewables sector for example can typically be 10-15 years – is a challenge in an emerging sector where future market prices for hydrogen and power could fluctuate significantly.

A combination of public and private sector investment will be crucial in the early development of the sector. In Scotland, the Scottish National Investment Bank is seen as having an important role given its mandate for catalysing new markets and its significant financial firepower. Although it looks to deploy capital on commercial terms for commercial returns, it has a slightly higher risk appetite than the wider capital market.

The Scottish Futures Trust's experience in helping new sectors develop and understanding of the bigger picture in terms of policy and ambitions across the Scottish and UK governments will also be valuable.

Early public support in proving out the investment case in hydrogen should pave the way for private capital to get involved, whether as part of the same funding round or for future projects.

"There is a lot of analysis being done right now about what 'good' should look like in the hydrogen market and that is helping potential funders form views on which business models we may end up with which will ultimately support investment cases. I think we will start to see things firming up in the next 12 months," said one contributor.

THE CHALLENGES IN BUILDING THE INVESTMENT CASE FOR HYDROGEN IN SCOTLAND

VISIBILITY ON GRID/ELECTRICITY MARKET ISSUES

The development of hydrogen will be closely linked to the electricity grid and the wholesale power market.

Delays in securing grid connections have long been a major blocker for the renewables industry with a lengthy pipeline of projects waiting many years.

Moves to reform GB's electricity market in the years ahead are also seen as having potentially significant implications.

The UK Government is currently considering consultation responses to the Reform of Electricity Market Arrangements (REMA), which could see the introduction of Locational Marginal Pricing (LMP) aimed at reflecting the cost to buy and sell power at different locations.

LMP could relieve electricity network constraints by incentivising location specific investment in areas such as hydrogen electrolysis and storage. However, it could also increase risk to investors in new generation such as the ScotWind projects which could jeopardise Scotland's renewable and hydrogen ambitions.

A study[12] by academics at the University of Strathclyde into LMP recently concluded that although the system has merit, there are "very real concerns about the potential impact of reform on cost of capital".

Uncertainty around the outcome of REMA comes at a time when investors are already digesting the impact of the windfall levy on generators imposed by the UK Government amid high prices for consumers.

"For investors there is a lot to be cautious about right now. We've a long way to go before construction of big offshore projects gets under way and there's a risk investors may hold back which would in turn delay the development of hydrogen," said one contributor.

Another said the electricity market "simply isn't fit for purpose to allow and incentivise the development of other forms of low carbon energy use".

An example was given of a prime potential hydrogen production location close to a major industrial facility and transport user.

"Unless that location was next to a renewable generator you'd have to buy power off the retail market which is benchmarked against gas and not renewables.

"That means the North of Scotland, which is more than self-sufficient in renewable energy, pays the highest power prices in Europe. If a market mechanism could be devised to incentivise electrolysis in optimal locations then I think we could have a really vibrant sector developing in the best locations."

THE CHALLENGES IN BUILDING THE INVESTMENT CASE FOR HYDROGEN IN SCOTLAND

STREAMLINING PLANNING & CONSENTS

Developers looking to progress a hydrogen project in Scotland face having to deal with a fragmented legislative and regulatory landscape.

Different consenting regimes apply depending on factors including capacity, location and method of production. The complexity is magnified by the fact each authority works to different timescales and are often statutory consultees in each others' consents process.

Consenting processes also vary across UK legal jurisdictions. While Scottish Ministers have consenting powers under the Electricity Act, changes to the act itself along with other energy, regulatory and safety legislation and policy, are reserved to Westminster.

"The whole consenting process needs streamlining as it ultimately costs developers and investors time and money and there's a risk they will look elsewhere," said one contributor.

The Scottish Government has committed to a review of existing legislation, regulation and standards, to identify and remove potential barriers to the growth of the hydrogen economy.

The Scottish planning system will be a crucial enabler of projects, and the National Planning Framework (NPF) 4 recently approved by the Scottish Parliament aims to aid the development emerging low-carbon and zero emissions technologies including hydrogen.

However, there are concerns that an already-stretched system - where achieving consent for renewable energy projects can take years - is underprepared to deal with a raft of applications in what will be a new unfamiliar sector for planning officials.

One contributor saw merit in the development of a pre-application process to smooth the journey through the planning system.

"It would be a way for developers to have early discussions with planners about what they are looking to do and identify any potential issues before submitting a full application."

THE CHALLENGES IN BUILDING THE INVESTMENT CASE FOR HYDROGEN IN SCOTLAND

SECURING THE RESOURCES

With many other countries looking to rapidly scale low-carbon hydrogen production in the years ahead, demand for key equipment such as electrolysers will rise significantly.

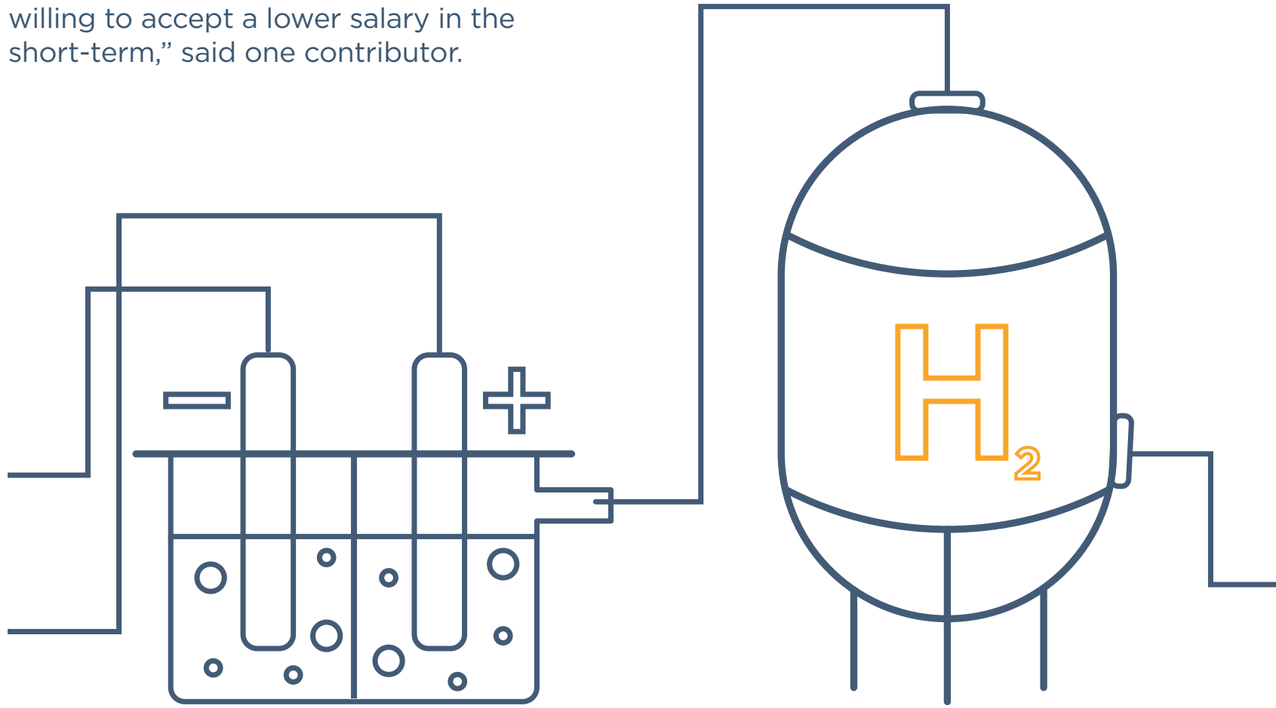
Although the supply chain is starting to ramp up production, in areas such as transport manufacturers are reluctant to commit significant resources into developing new vehicles for an unproven market.

Even where vehicles are available, upfront costs are a multiple of existing diesel models and investing in the necessary maintenance capacity would also be a major issue for front-line service vehicles.

Ensuring Scotland has the people with the skills needed for the development of a hydrogen economy will also be critical across construction, commissioning, engineering, maintenance and technical specialists needed for safety codes and standards. Work is underway through organisations including Scottish Enterprise and Skills Development Scotland to build up industry capacity.

Although there is potential for oil and gas sector workers to transfer into the hydrogen sector, the current resurgence of interest in North Sea activity could also see fierce competition for key skills.

“Salaries in the oil and gas sector are likely to be more attractive than in hydrogen as it has established revenue streams. However, there will also be those actively want to work in a low-carbon sector and may be willing to accept a lower salary in the short-term,” said one contributor.



NEXT STEPS

The opportunities for developing a low-carbon hydrogen economy in Scotland are undoubtedly exciting, but the hurdles that will need to be overcome are not to be underestimated.

Much good progress has been made at both a Scottish and UK level in terms of setting the vision, but the challenge now is translating that into delivery.

Although there are many fantastic examples of hydrogen in action in Scotland, there is also some disappointment that overall progress in recent years has been slower than hoped. A number of significant projects have suffered setbacks and delays and it will be important to learn lessons if Scotland's stretching targets for low-carbon hydrogen are to be achieved.

The target of 5GW of low-carbon hydrogen production by 2030 would represent an increase of some 1,000-fold on where we are today. Although major projects like Acorn could provide a sizeable proportion of that, many smaller projects will also need to come on stream in a relatively short timeframe.

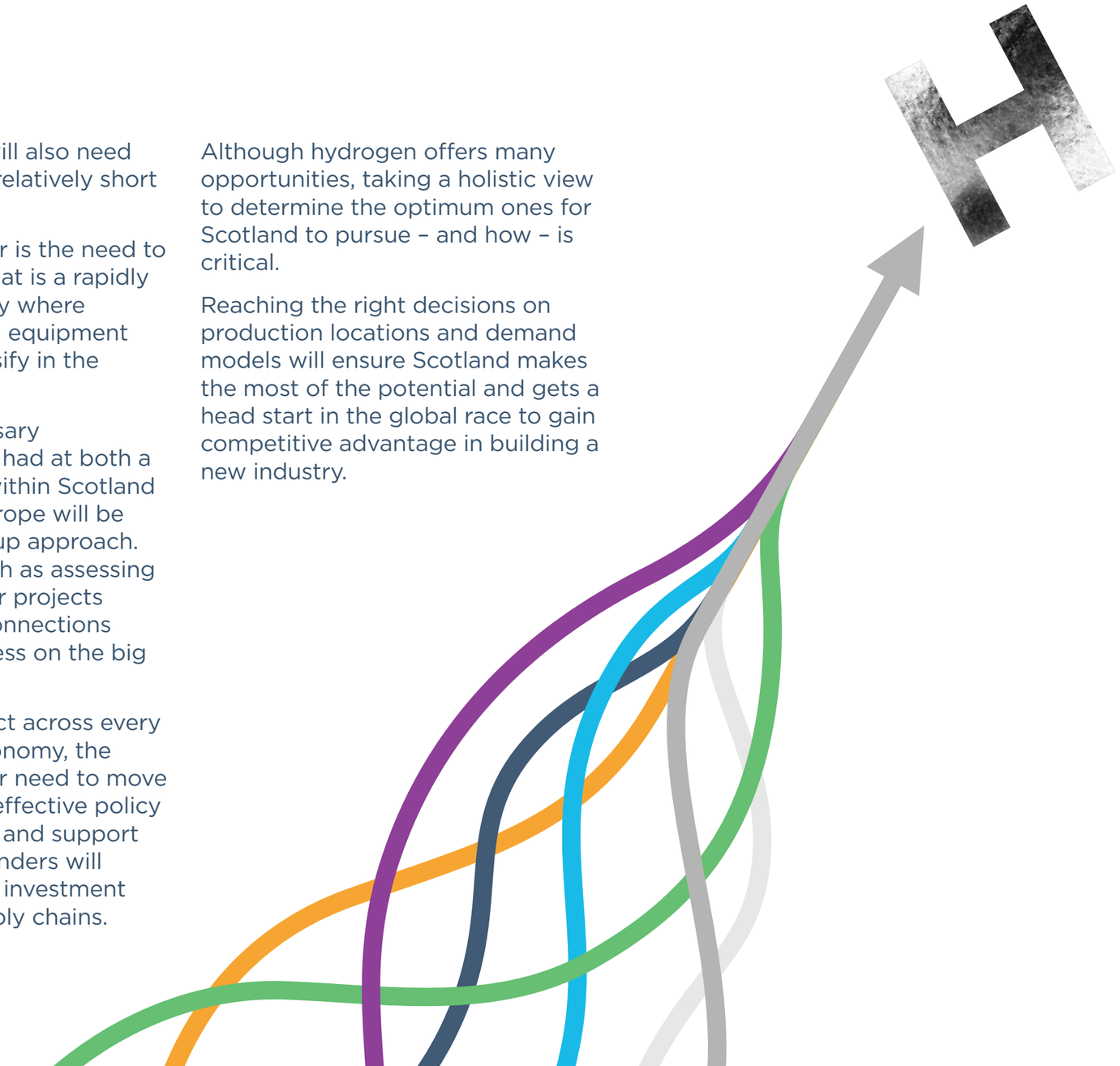
What is abundantly clear is the need to now move at pace in what is a rapidly emerging global industry where competition for funding, equipment and skills will only intensify in the years ahead.

Ensuring that the necessary conversations are being had at both a macro and micro level within Scotland and with the UK and Europe will be vital to ensure a joined-up approach. Bottlenecks in areas such as assessing planning applications for projects at a local level or grid connections could quickly put progress on the big picture at risk.

Given its potential impact across every aspect of Scotland's economy, the public and private sector need to move forward together. With effective policy levers, demand visibility and support in place, industry and funders will have confidence to take investment decisions and build supply chains.

Although hydrogen offers many opportunities, taking a holistic view to determine the optimum ones for Scotland to pursue – and how – is critical.

Reaching the right decisions on production locations and demand models will ensure Scotland makes the most of the potential and gets a head start in the global race to gain competitive advantage in building a new industry.



HYDROGEN EXPLAINER

WHAT IS HYDROGEN?

The most abundant chemical element, hydrogen makes up an estimated 75% of the mass of the universe. A colourless, odourless, highly flammable gas, burning hydrogen does not emit any carbon dioxide.

HOW IS IT PRODUCED?

Hydrogen can be produced from a number of different sources including natural gas, nuclear power, biogas and renewable power.

The most common types of hydrogen production include:

GREEN HYDROGEN –

produced via electrolysis using electricity to split water into hydrogen and oxygen. No greenhouse gas emissions are produced, although there may be emissions depending on how the electricity needed is generated.

BLUE HYDROGEN –

mainly produced through a system called reforming, where steam is reacted with natural gas to create hydrogen and carbon dioxide. The carbon dioxide is captured to enable the process to be described as low carbon.

GREY HYDROGEN -

The most abundant chemical element, grey hydrogen is currently the most common form of hydrogen production. It uses steam methane reformation but without capturing carbon dioxide. Black and brown hydrogen use coal or lignite to produce hydrogen. Grey hydrogen is already widely used in sectors including production of ammonia, steel and methanol as well as oil refining.

HYDROGEN AND THE SCOTTISH ECONOMY

PRODUCTION

Achieving the Scottish Government's targets for renewable and low-carbon hydrogen production would see the creation of a major new industry in Scotland.

Although still a nascent sector, there are a growing number of companies already pursuing hydrogen production opportunities. The Scottish Offshore Wind to Green Hydrogen Opportunity Assessment[13] identified over 100 businesses that are interested or active in green hydrogen production alone.

A report[14] by Scottish Enterprise, the Offshore Renewable Energy Catapult and the Net Zero Technology Centre into the potential for the development of early, low-carbon hydrogen production concluded that "with the correct policy and financial incentives, Scotland is incredibly well positioned to produce vast quantities of blue and green hydrogen in multiple locations across the country".

These include the islands which could utilise vast offshore wind resources, while mainland sites strategically located close to infrastructure, future local demand and export routes could also be suitable.

Investment in hydrogen production assets could also benefit from avoided constraint costs currently paid to wind farm operators to turn down output due to the network being unable to transport the power to where it is needed.

The experience, infrastructure and supply chain from the oil and gas sector could be drawn on to be able to produce blue hydrogen at scale in a relatively short timeframe while work to develop green hydrogen production continues to gather pace.

Acorn Hydrogen's plans to build a 200MW blue hydrogen plant at the St Fergus gas terminal as part of the wider Acorn CCS project is by far the highest profile production project in the pipeline.

Green hydrogen projects being progressed include ScottishPower and Storegga's Cromarty Hydrogen Project[15], which could deliver up to 20 tonnes of green hydrogen a day to fuel heating in distilleries, and potentially other local manufacturing businesses.

PROJECT FOCUS:

Acorn Hydrogen[16] – located adjacent to the St. Fergus gas terminal, will turn North Sea natural gas into low-carbon-burning hydrogen while safely capturing the CO2 emissions. The project would have the capacity to produce more than 10TWh of hydrogen a year.

HYDROGEN AND THE SCOTTISH ECONOMY

EXPORT

Domestic demand is seen as an important foundation for a hydrogen economy, but the potential for Scotland to be a major exporter is also a significant opportunity.

Exporting hydrogen to other parts of the UK and Europe will offer a valuable new revenue opportunity for renewable energy developers.

Existing renewable capacity and the pipeline of new onshore and offshore wind projects raises the prospect of an oversupply at a time when demand for hydrogen in Europe will accelerate rapidly with the EU setting a target to import 10 million tonnes by 2030.

The Scot2Ger[17] study, led by industry and supported by the public sector, highlighted the strong position Scotland is in to become an exporter of green hydrogen to a ready-made market in Germany in particular.

The study concluded that there was already demand from potential customers who would take Scottish green hydrogen if it was available now.

PROJECT FOCUS:

The 'Hydrogen Highway'[18] pilot by the Net Zero Technology Centre and ERM will export green hydrogen in liquid form from Scotland to the Port of Rotterdam. The port already imports 13% of Europe's energy and has ambitions to become the continent's Hydrogen Hub.

INDUSTRY

The pressure to decarbonise - along with security of supply and potential long-term cost savings - means adoption of low-carbon hydrogen is increasingly being assessed as a potential option by major energy users.

In Scotland INEOS and Petroineos, the owners of the huge Grangemouth complex, are planning to use hydrogen combined with carbon capture[19] via the Acorn project in a move which would reduce CO2 emissions at the site by more than a million tonnes a year.

Research is currently underway with other major energy users in Scotland to understand the potential scale of hydrogen demand as the Scottish Government looks to establish sector-coupling hydrogen production hubs capable of simultaneously servicing industry, transport and heat.

The hubs will aim to create economies of scale by aggregating local demand across multiple sectors, driving cost efficiencies and facilitating knowledge sharing.

The extent to which business users will consider making the switch to hydrogen will depend on issues including costs, proximity to a production hub and availability of infrastructure.

Sectors such as whisky production are seen as among the most promising given the challenges many remote distilleries face in decarbonisation through electrification.

"Finding these early adopter sectors and businesses will be really important as they will support the investment in the production which in turn other users could tap into," said one contributor.

Even though costs in the early stages of hydrogen adoption will be higher than say natural gas, the potential reputational benefits of switching to a lower carbon fuel could also be important for some businesses.

"Hydrogen's role in reducing carbon footprint will be a valuable benefit in terms of marketing for some organisations and will help underpin the business case," pointed out one contributor.

HYDROGEN AND THE SCOTTISH ECONOMY

PROJECT FOCUS:

Scottish spirits producer Arbikie[20] is on track to become the world's first distillery to be powered by green hydrogen. The distillery, based on a farm at Lunan Bay, Montrose, is building a 1MW wind turbine which will power an electrolyser to produce hydrogen which will be used in a new hydrogen-ready boiler.

POWER GENERATION

The potential for both blue and green hydrogen to replace natural gas in thermal power stations could provide a significant offtake for Scottish production as well as aiding decarbonisation.

"The sort of volumes needed for hydrogen in power generation are very significant so that could really kickstart the sector by establishing large demand early on," pointed out one industry expert.

Existing power stations could be adapted to be able to use a proportion of hydrogen in their fuel mix, and work is underway to assess the technology that would be needed.

Hydrogen-fuelled turbines could also provide valuable electricity grid balancing services, replicating the function currently provided by fossil fuel-powered generation.

However, the need to be able to quickly access large quantities of fuel to meet grid demands coupled with the low volumetric density of hydrogen means large-scale storage close to production is seen as the optimal combination.

Although salt caverns are the most obvious locations for storage, Scotland's geology means that is not an option. There are research projects underway, including one based at the University of Edinburgh[21], looking at the potential to store hydrogen in porous rocks, similar to the approach taken for carbon capture and storage.

Transporting hydrogen from Scotland to power stations in England using pipelines is also a possibility, and initiatives like National Grid's FutureGrid[22] project is looking into the potential for full-scale conversion of the existing National Transmission System (NTS) to transport hydrogen. A separate initiative, Project Union, is looking at development of a hydrogen 'backbone' to link industrial clusters around the country.

PROJECT FOCUS:

Perth-headquartered SSE is at the forefront of developments aimed at bringing hydrogen-powered generating stations online and is involved in the Keadby[23] project in North Lincolnshire which could be one of the world's first large-scale 100% hydrogen-fuelled power station.

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TRANSPORT

Hydrogen could provide decarbonisation opportunities across transport sectors where full electrification is challenging, including road, rail, shipping and air travel.

Although a relatively immature technology for transport, there are a number of small-scale projects underway in Scotland to trial its use notably in Aberdeen where a fleet of hydrogen vehicles including buses and waste vehicles, is on the roads. That project, which initially began with public sector fleets, is now seeing private sector demand flourish, thanks to provision of two publicly accessible refuelling stations.

For road transport, although hydrogen cars are not seen as challenging the dominance of electric vehicles (EVs), hydrogen could step in where they are not suitable due to range issues or grid charging demands. Hydrogen vehicles could also fill gaps in electric van fleets where home-based operators are unable to charge vehicles. Opportunities for hydrogen in haulage are being actively looked at and a consortium led by Glasgow-based Hydrogen Vehicle Systems is currently developing a world-first, autonomous zero-emission HGV.

Hydrogen trains could also be deployed in parts of Scotland where electrification of lines would not be cost-effective.

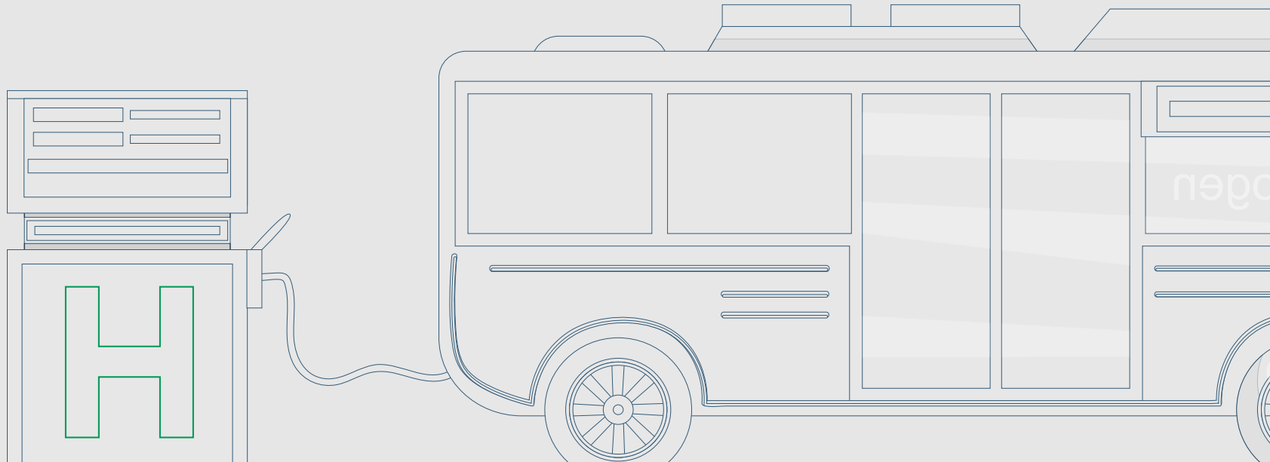
“Rail demand would be an excellent base-load for a large-scale hydrogen production hub which could be sited in a rural area where perhaps there was also whisky production which could offer another potential offtake,” said one contributor.

The Scottish Government has committed to working with developers of hydrogen fuel cell trains to accelerate their development and deployment in Scotland.

The potential for hydrogen-powered ferries is also an interesting prospect for Scotland given there are more than 60 routes in operation. Although there are no current plans to introduce hydrogen on Scotland’s main ferry routes, the HYSEAS III[24] research project in Orkney is looking at the potential for a hydrogen-powered ferry to operate round the islands where hydrogen is already produced from constrained renewable energy which would otherwise be wasted.

PROJECT FOCUS:

The Aberdeen Hydrogen Hub[25] is a joint venture between bp and Aberdeen City Council that aims to deliver a scalable, green hydrogen production, storage and distribution facility in the city powered by renewable energy. The first phase involves building a hydrogen refuelling facility powered by a solar farm. It aims to produce over 800 kilograms of green hydrogen per day from 2024.



HYDROGEN AND THE SCOTTISH ECONOMY

DOMESTIC HEAT

Although Scotland is home to a pioneering project to explore the potential for green hydrogen to be used in homes, the Scottish Government's current position is that it does not consider hydrogen will play a "central role in the overall decarbonisation of domestic heat".

It sees potential for some parts of the gas grid to be converted to 100% hydrogen in the 2030s and beyond, but it would be in specific circumstances such as rural island areas.

The Scottish Government points out the potential for hydrogen for heating buildings depends upon strategic decisions by Westminster and said it will continue to "urge the UK Government to accelerate decision-making on the role of hydrogen in the gas grid".

PROJECT FOCUS:

SGN's H100 Fife[26] project is developing a world-first hydrogen network to bring renewable hydrogen into homes in 2024, providing zero-carbon fuel for heating and cooking. In the project's first phase, the network will heat around 300 local homes using low-carbon gas produced by a dedicated electrolysis plant, powered by a nearby offshore wind turbine.

This report was compiled with the assistance of a number of industry experts, which included:

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Footnotes

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