Regen Hydrogen Insight Paper
Building the hydrogen value chain

Author: Johnny Gowdy, director, Regen

A critical fuel for our net zero future

Hydrogen is set to play a critical role to enable the UK economy to achieve net zero carbon. As well as providing a low carbon energy source for difficult to decarbonise sectors such as heavy transport, aviation and various industrial processes, hydrogen could also play an important role in system balancing as a multi-vector fuel, using very low-cost electricity during times of over-supply to convert, store and transport renewable energy for applications across the energy system.

Hy to Hydrogen, the first in our series of hydrogen insight papers, described how hydrogen could provide a low carbon fuel for some of the most difficult to decarbonise sectors, and outlined the scale of opportunity for the UK to create a new and exciting industrial sector. In this insight paper, **"Building the hydrogen value chain"**, we will look more closely at the complexity and richness of the hydrogen value chain[1], and consider how its development can best be supported by targeted policy interventions.

As this paper sets out, there are strong arguments to support policy intervention to encourage innovation, develop new consumer markets and to accelerate investment in hydrogen production and distribution assets. Getting to scale, and reducing costs, will be critical if hydrogen is to reach its full potential in supporting the transition to net zero carbon.

Policy makers need to tread carefully, however. Hydrogen should not be considered as just a replacement for natural gas or akin to electricity. Its complex and multifaceted value chain, as well as its relative market immaturity, requires a more strategic approach. Specifically, this paper highlights the risk of market distortion that could entrench inappropriate manufacturing or supply chain technologies. Instead, policies should focus on nurturing consumer demand-led markets that will continue to drive innovation, carbon reduction and cost efficiency, and enable low carbon hydrogen to deliver its full economic and decarbonisation value.

Hydrogen is not the same as natural gas or electricity generation

It would be an easy mistake to think that hydrogen can be considered as a direct equivalent of natural gas and that it will easily slot into the same supply chain and market structures. It would be equally wrong to assume that policy measures that have been used to support electricity generation can simply be ported over to secure investment into low carbon hydrogen production.

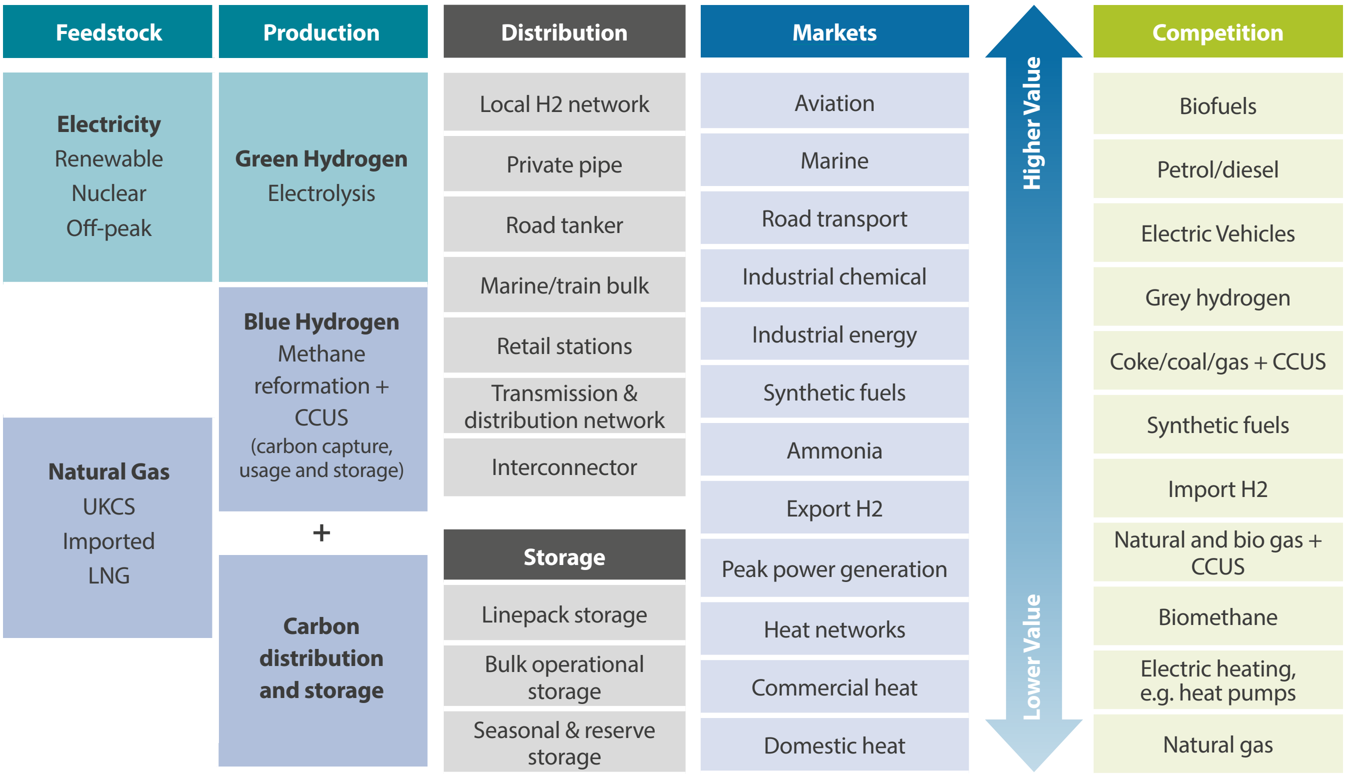
If our aim is to get the maximum benefit from the development of a hydrogen value chain, we need to think about the nature of the emerging hydrogen markets and think strategically about how hydrogen fits into a net zero energy system.

The reference to hydrogen market*s* in the plural is deliberate. Natural gas and electricity can, by-and-large, be considered as homogenous commodities; easily traded, fungible and with an easily discernible market price. The hydrogen sector, at least at this early stage of development, is better considered as a set of related but distinct markets and supply chains. Perhaps in the future an integrated hydrogen market will emerge, but this is by no means certain and will depend on the nature of its physical supply chain as well as its multi-vector[2] tradability.

1 Value chain or supply chain – annoying terminology. We have used supply chain to refer to the physical or logistical chain, value chain to refer to the wider market and commercial value proposition.

2 Multi-vector – across energy uses for power generation, heat, industrial processes and transport as well as an energy storage medium and feedstock for other fuels.

The hydrogen value chain



It is important that policy makers recognise and consider the multifaceted nature of the hydrogen value chain:

- Hydrogen requires a manufacturing process for which there are several technology options and feedstocks.
- There are distinct markets and value propositions for hydrogen products. These range from existing uses[3], new high-value applications in transport and industrial processes, and potentially lower-value applications as a fuel for heating or to generate electricity.
- Within these individual markets, low carbon hydrogen may be competing against a wide range of alternative solutions including grey hydrogen, natural gas, diesel, electricity, biofuels, coke, aviation fuel and battery storage.
- Hydrogen itself may be considered a feedstock for chemical processes and for the manufacture of synthetic fuels, potentially in combination with captured carbon. Synthetic hydrocarbon fuels could play a significant role in achieving net zero in otherwise difficult to decarbonise industries such as aviation.
- Hydrogen could also become an important multi-vector balancing fuel, enabling the transmission and storage of very low-cost renewable electricity produced at times when electricity supply exceeds demand.
- Hydrogen distribution could take many forms including onsite production, local and private networks, road, marine and rail bulk tankers, as well as through gas distribution pipelines.
- Hydrogen has physical properties (energy density) and qualities (purity) that make it suitable as a low carbon fuel for different markets.

In short, the hydrogen value chain is complex with multiple distribution channels, markets, and competitors. This is good news in terms of the opportunity to develop an exciting new industry, but it does mean that policy makers need to tread very carefully when thinking about market-building policy interventions.

3 The Energy White Paper Dec 2020: "UK currently makes up to 27 TWh annually", by grey hydrogen produced, close to demand customers, mainly be methane reformation with resulting high carbon emissions (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/943807/201214_BEIS_EWP_Command_Paper_LR.pdf) Energy Research Partnership https://erpuk.org/wp-content/uploads/2017/01/ERP-hydrogen-report-oct-2016.pdf

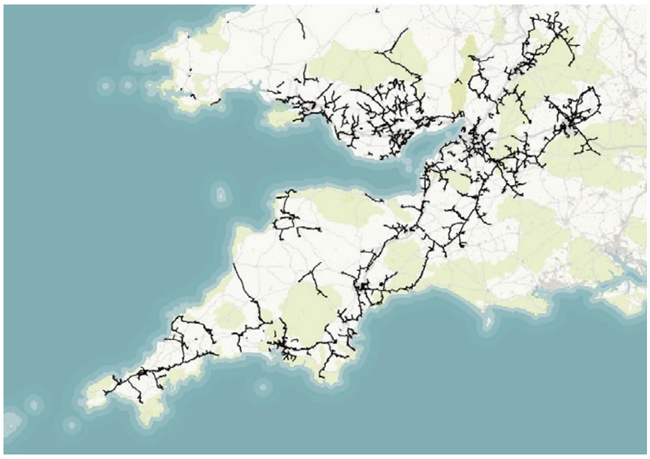
Storage and distribution will be critical elements of the value chain

While the focus for policy makers may be investment in production and the development of consumer markets, the assets and investment required to distribute and store hydrogen are critical elements of the value chain.

In the case of natural gas, the UK has reached the point close to a just-in-time supply chain, allowing the UK to operate with a reduced reserve gas storage capacity[4] whose primary role has become peak price arbitrage and to provide a reserve capacity.

Natural gas is continuously injected into the networks at beach landings from the UK Continental Shelf gas fields[5] and interconnectors from European pipelines. This is augmented by LNG imports. So, the UK relies chiefly on the inherent "linepack" storage, compressed within the UK's 7,500 kilometres of transmission and 280,000 kilometres of distribution network, which is depleted and replenished (re-pressurised) in a daily cycle. On a typical cold day, this network can deliver over 400 million cubic metres of natural gas, carrying the equivalent of over 5 TWh[6] of energy.

With little processing, on-tap supply and a high energy content, the distribution of gas is relatively cheap and efficient. This has allowed the gas network to reach into 85% of UK homes since the "dash for gas" in 1980s.



The UK gas network has nearly 7,500 km of high pressure transmission pipework and 280,000 km of distribution network.
Picture: Peter McDermott and Wales & West Utilities

4 Around 12 days of average gas demand or 6 days of winter demand.

5 UKCS gas production has fallen and in 2019, met around 45% of 957 TWh UK gas demand https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/912021/DUKES_2020_Chapter_4.pdf

6 For more detailed explanation see Regen The Decarbonisation of Heat

Compared to natural gas, a hydrogen-based supply chain will require much more logistical and inter-seasonal storage capacity, and a far greater overall distribution capacity, per unit of energy supplied. The reasons for this are twofold:

1 Hydrogen production process

Hydrogen introduces a production process into the supply chain, with a significant capital investment in manufacturing plants, as well as new operational constraints. To balance supply and demand efficiently, there is an economic and logistical optimisation between manufacturing plant capacity utilisation and the need for greater hydrogen storage capacity. This will become especially critical if hydrogen is used to meet highly seasonal demand such as domestic and commercial heating.

2 Lower energy density by volume

At circa 3.3 kWh per cubic metre under ambient conditions compared to natural gas at circa 11 kWh per cubic metre, hydrogen has a far lower volumetric energy density. This means that hydrogen will have to be compressed to a much higher pressure, and delivered at a higher flow rate, to deliver the same energy content. As an added challenge, hydrogen has a greater propensity to leak, leading to potential losses in the supply chain.

One key implication of hydrogen's lower energy density is that the existing UK gas networks, if they were wholly converted to a 100% or high hydrogen blend, would not be able to store and deliver the same daily energy supply without significant network investment and increased operating costs. How much additional cost and asset investment this will entail has not yet been quantified, and this is one of the key questions that will hopefully be addressed by innovation projects like **HyNTS FutureGrid** and **H100 Fife**.

Comparison of energy densities – hydrogen and natural gas

Gross Energy (Higher Heating Value)	**Hydrogen**	**Natural Gas** (UK Transmission[7])	**Density ratio H2 : NG**
Energy per mass (kWh/kg)	39.4	13.8	1.8 : 1.0
Energy per volume (kWh/m^3 @ atm)	3.3	11.0	1.0 : 3.4

7 DUKES Calorific Value 2019.

A capital-intensive production process, together with the very low energy density of hydrogen by volume, has profound implications for the economics of hydrogen distribution and storage, and the overall structure of the supply chain. For example, when assessing whether the optimal supply chain for a particular hydrogen market is best served by a small number of very large manufacturing plants, enjoying economies of scale in production, or by a larger number of distributed production facilities located near to consumers to allow lower storage and distribution costs.

The jury is still out on this question[8], but evidence from the existing hydrogen market and the new commercial hydrogen projects that we identified in our previous paper suggest that the initial market driver is towards production plants that are located within industrial and chemical process clusters and transport hubs, with relatively short or onsite distribution channels.

The optimisation and shape of the supply chain will depend heavily on what markets hydrogen is to supply; it is also strongly linked to the choice of manufacturing process. There is not a fixed view of this yet, but as a rough generalisation:

Blue hydrogen	Produced by methane reformation, blue hydrogen would naturally lend itself to a more centralised value chain based around very large production facilities (including the requisite CCUS) and large-scale storage linked to big industrial clusters and potentially to a large-scale hydrogen network.
Green hydrogen	Produced by electrolysis, green hydrogen could support a more decentralised value chain with a wide range of plant sizes tailored to each market segment including industrial clusters, transport hubs, district heat solutions and localised hydrogen networks.

Hydrogen costs will fall but remain high compared to natural gas[9]

The cost of both blue and green hydrogen is currently very high compared to natural gas and to grey hydrogen. Interest in hydrogen as a future fuel is predicated on the expectation that economies of scale and innovation will reduce costs significantly over the coming decade.

How far and how quickly costs will fall is still uncertain. Clean hydrogen could become competitive with grey hydrogen and with other refined fuels in the near term, especially if a more aggressive carbon tax is implemented. Industry targets for cost reduction suggest a potential factory gate levelised cost of production of 5p-7p per kWh. Green hydrogen, while initially more expensive, is expected to outperform blue hydrogen in the medium term[10].

Even with a significant reduction, the final cost of hydrogen to the end consumer is projected to remain markedly higher[11] than the current cost of natural gas. Key hydrogen levelised cost drivers include feedstock costs, conversion efficiency, production costs and CCUS for blue hydrogen, plus there are additional distribution, logistical and seasonal storage costs. Retail margins may also be higher given the increase in commodity value, inventories, and overall supply complexity.

8 Studies focused on H_2 production cost reduction tend to assume very high asset utilisation. Studies considering the operability of a H_2 systems tend to assume higher production capacity and by implication lower utilisation.

9 We will be looking at the cost drivers and cost reduction potential in our next Regen hydrogen blog.

10 Wood Mackenzie analysis on hydrogen production costs: www.woodmac.com/our-expertise/focus/transition/hydrogen-production-costs-to-2040-is-a-tipping-point-on-the-horizon

11 Getting hydrogen consumer retail costs to less than an average of 9p per kWh would be a significant achievement. Natural gas currently retails to domestic consumers at circa 4.5p per kWh.

As costs fall, it is expected that hydrogen will first become competitive with grey hydrogen, diesel, and petrol as a transport fuel, and as an industrial fuel for those industries that are subject to increasing carbon tax penalties[12]. If the industry is to be "consumer-led", these are the markets that policy makers should target first.

Pushing hydrogen as a replacement for natural gas for heating would be a big strategic decision and would require long-term policy interventions, such as applying a very high carbon tax while providing a long-term fuel subsidy. It is likely that hydrogen for heating will emerge from a much more targeted strategy, providing fuel for heat networks and localised distribution networks in areas that are otherwise hard to decarbonise.

Some commentators have suggested that using hydrogen for domestic heating would allow consumers to avoid the cost and disruption of energy efficiency measures. This would be a mistake; high hydrogen costs and seasonal peak demand mean that using hydrogen for domestic heating would require just as high levels of energy efficiency as any other low carbon heating option.

What does this mean for policy makers?

The scale of opportunity and the range of technological and market challenges[13] to be overcome provides a strong case for policy and regulatory intervention to enable the development of the hydrogen energy sector.

Policy support for the hydrogen sector could also be justified as part of a wider industrial strategy that will help transition skills and capabilities from the UK's oil and gas, chemical processing, and heavy industries to a net zero economy. Development of the hydrogen value chain would therefore sit well within the UK's overall energy mix and, if produced in the form of "green hydrogen" via electrolysis, could further support the expansion of renewable energy and other green technologies.

This clearly presents a dilemma. Policy makers want to move quickly to expand hydrogen markets and to secure the UK's leadership position. Plus, there is the imperative to deliver low carbon solutions for key industrial and transport sectors to meet the UK's interim decarbonisation targets. Scaling up the sector is therefore essential.

Ambitious targets

The UK Energy White Paper[14] has proposed a target of 5 GW of low carbon hydrogen capacity and a production target of 42 TWh by 2030.

Scotland's ambition, as set out in its Hydrogen Policy Statement, is even greater, with an ambition to reach 5 GW of hydrogen capacity in Scotland alone by 2030, and to become a major exporter of green hydrogen, utilising Scotland's offshore wind resource, by 2045[15].

However, as discussed, the structure of the hydrogen value chain is not yet defined and will depend on the alignment of many market variables. There is also industry lobbying at play, representing various incumbent interests[16], which policy makers need to navigate through. Inappropriate policy interventions, or a clumsy approach that favours one particular hydrogen producer, technology or distribution channel, risks distorting the market and inhibiting future innovation. Such an outcome could have long-term consequences and ultimately impede the full potential of the value chain.

12 At present, carbon prices at EU ETS €25 are too low and arguably need to rise to circa €75 to drive deep industrial decarbonisation and fuel switching.

13 An obvious challenge is the current price point of green and blue hydrogen compared to grey hydrogen and to natural gas and the absence of a universal and proportionate carbon price.

14 UK Energy White Paper December 2020 – 5 GW capacity and 42 TWh by 2030 which implies a 95% utilisation rate.

15 Scottish Government Hydrogen Policy Statement December 2020.

16 See an interesting academic paper on the risk posed by Incumbent Discourse Coalitions www.sciencedirect.com/science/article/pii/S2210422420300964

One approach would be to set out a clear set of criteria against which to measure policy outcomes. The table below gives an illustration of what those criteria might be. These criteria are not unique to hydrogen and mainly underline the message that interventions need to be based on a holistic view of the policy objectives and aligned with an overall industrial strategy.

Building a hydrogen value chain
Success criteria for sector intervention

1. It must be very low carbon – there is no case for policies that might continue the production of high carbon grey hydrogen, or inefficient production processes that are not compatible with a net zero energy future[17].
2. It needs to scale up quickly, to drive down costs and open new markets, but not to embed incumbents with less efficient solutions or at a pace that creates market volatility.
3. It needs to support on-going innovation and create opportunities for new disruptive solutions to replace older technology.
4. It should be market value and consumer led, encouraging investment where there is inherent customer value.
5. It should be competitive, avoiding the creation of new monopolies or incumbent-dominated markets.
6. It should be strategic. Interventions should support the UK's long-term energy strategy. For example, allowing green hydrogen to play a multi-vector role to support higher levels of renewable electricity and offshore wind.
7. It should create economic value, including long-term employment, skills, and export opportunities for UK businesses.
8. Interventions should be clear, manageable, and sustainable in terms of levy budget control, consumer or taxpayer value and the political support that follows. Policies that break budgets or lead to runaway boom and bust cycles should be avoided.

Against these criteria, UK policy makers might consider a range of policy interventions including support for innovation and technology development, supply side production and supply chain subsidies, sector specific measures and demand side interventions to create new consumer markets.

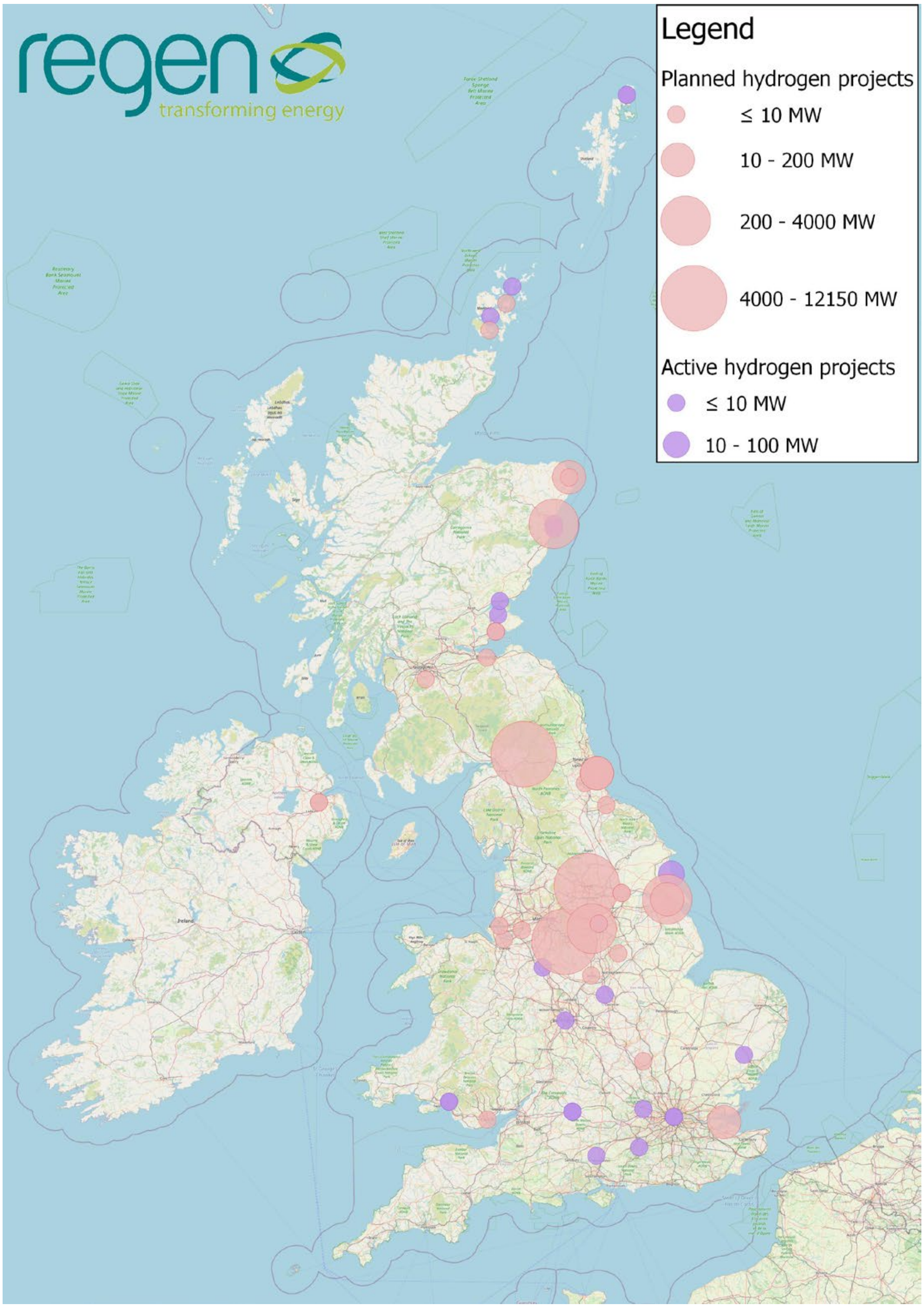
17 The CCC has suggested that hydrogen CCUS should be at least 95% efficient to be compatible with net zero. Consideration must also be given to carbon emissions from storage or usage of the hydrogen produced.

Innovation support – creating pathways, not steeplechases

Backed by excellent academic institutions and strong industrial collaboration, the UK has a global reputation for research and development, and early-stage technological innovation.

The UK has made significant progress via its support for innovation and demonstration projects, putting it in the vanguard amongst countries that are pushing the boundaries of new hydrogen technology.

Already this capability can be seen in the nascent hydrogen sector, with some great work going on at research centres and through collaborative partnerships such as H2 Wales and the HyPER project.



Our research suggests that the UK now has over 20 current hydrogen innovation projects[18], and more in the pipeline, ranging from new electrolysis plants and carbon capture demonstration projects to consumer trials involving transport and heating applications for hydrogen.

There are also several emerging hydrogen industrial clusters based near existing chemical processing plants in Teesside, Tyneside, South Wales, the Wirral/Runcorn, and the Firth of Forth. Hydrogen innovation features heavily in the recent UK Infrastructure Strategy and Energy White Paper, in which government detail plans to work with industry to deploy 5 GW of hydrogen production by 2030, supported by a new £240 million Net Zero Hydrogen Fund.

This funding does, however, need to be properly prioritised. A common criticism of innovation policy in the UK has been the failure to commercialise and build upon our research base in the later stages of technology development. Having done great research, we tend to drop the innovation ball (perhaps by overly relying on the market) whilst other countries with a more aligned industrial strategy forge ahead[19].

Developers have often criticised innovation funding in the UK for being a 'steeplechase', requiring innovators to jump ever higher hurdles, while the winners of support may be those whose main capability is writing good grant applications rather than those with a viable commercial technology. There has also been a tendency to scattergun initiatives without a joined-up strategy to lead solutions on a pathway from innovation to commercial development to industrialisation. This problem is certainly not unique to the hydrogen sector and, by contrast, there are examples such as offshore wind where innovation backed by a coherent industrial strategy has greatly accelerated technology commercialisation and cost reduction.

A consistent ask from industry and innovators is for better, joined-up programmes which create pathways for innovation to move through technology readiness levels (TRLs). An innovation pathway would enable those that are able to demonstrate success and potential, **against objective criteria that are set at an appropriate level for their TRL**, to be fast tracked to the next stage of development. The stage where this is most needed, the "valley of death", is the point at which technologies approach commercialisation but are not quite at the point of fully investable solutions.

This is not about picking winners, or stopping more speculative and ground-breaking research, but it should be about creating a more transparent environment in which the solutions with the greatest potential, not those adept at writing grant applications, can move forward quickly.

Production subsidy – providing confidence for investment

Support to encourage investment in new manufacturing technology and capacity will be essential, both to scale up the industry and to encourage new consumer markets. As previously noted, the UK government has now set a target of 5 GW of low carbon hydrogen capacity and 42 TWh[20] of low carbon hydrogen production by 2030. Even assuming a large chunk of this new production will replace existing grey hydrogen capacity, this level of growth would still require a near doubling of hydrogen demand from today's levels.

18 13 projects in the 'research' stage, 7 in the prototype/pilot stage and 3 projects that were trials that have now finished.

19 The Herman Hauser report that led to the Catapults for example.

20 5 GW to produce 42 TWh implies a very high capacity factor of 95%. Whether this is an intentional policy it does imply a certain sort of hydrogen supply chain that may, or may not, be optimal.

Producers and customers are looking for assurance of a growing hydrogen market, with security of supply and a high degree of price certainty. Before investors will commit capital to new manufacturing assets, they need to be confident of the rate of hydrogen demand growth in each of their market segments. Demand growth will in turn depend on the government's net zero policies. Meanwhile, new customers of hydrogen in transport and industry must be confident that supply will be available at a competitive price.

For hydrogen producers, this stability might come in the form of revenue support and a firm price commitment, such as has been provided for the offshore wind sector. The challenge for policy makers, however, is to provide this level of revenue assurance without locking less efficient producers into the market or inadvertently creating barriers for new entrants. Policy makers will also wish to avoid distorting the downstream value chain by encouraging the production of the wrong hydrogen products delivered through the wrong distribution channels and potentially stimulating inappropriate, low-value hydrogen use.

A simple Contract for Difference (CfD) approach may not be appropriate

A CfD scheme is a particular form of production subsidy which has worked well for offshore wind. It provides a subsidy of **the difference** between the prevalent energy wholesale **reference price** and a contract **strike price** for an agreed **contract term**[21]. The strike price should guarantee a revenue stream that delivers an **acceptable rate of return** on investment for producers. This could be set either via a **competitive auction** or **by negotiation**. Auctions can be divided into different **technology pots** and further levy budget sub-allocations **or minima**.

A feature of the CfD scheme is the imposition of a negative subsidy if, in the future, the reference wholesale price exceeds the strike price. With volatile and very low CfD strike prices now anticipated for renewable electricity this payback feature is now a real possibility, meaning that the contract strike price is expected to become more of a price guarantee rather than a straight subsidy.

So, within the CfD scheme there are a lot of potential policy levers that could be used to tailor an appropriate production subsidy for hydrogen. There are, however, several practical issues that policy makers will need to consider in the scheme design, and a number of potential pitfalls that could negatively impact the future hydrogen value chain development.

Some of the practical challenges include the setting of the CfD reference price and the control of the levy budget. In the case of a traded commodity such as electricity, the reference wholesale price is relatively transparent and easy to index. In addition, a fundamental assumption of the CfD mechanism is that the subsidy recipient is a price-taker and not a price-setter. If the CfD contract holders become price-setters, and can manipulate the market reference price, then it becomes impossible to manage the levy control budget and there is also the risk that the CfD could be used as an anti-competitive barrier against new entrants.

Already, the price-taker assumption for renewable electricity is under pressure, and this is one reason why the government has had to introduce some floor price rules to curtail subsidies when electricity wholesale prices become negative. It is also a reason why the CfD strike price scheme will probably need to be replaced (perhaps with a floor price scheme) as the proportion of renewable electricity in the system increases.

21 CfD terms are normally 15 years however for nuclear a 20 year term has been agreed.

A more complex CfD revenue model may be required

The starting point for the design of a hydrogen production subsidy is quite different to that of renewable electricity.

Hydrogen does not have a transparent or easily referenced wholesale price[22] and it may not be right to think of there being one single hydrogen market. The price of hydrogen will be a function of **different attributes**, such as the product quality and its location. In many ways, trading hydrogen is much more like trading refined oil products, which, as any oil trader knows, is about product, time, and location.

Setting the appropriate strike price is also problematic. The 'vanilla' electricity CfD strike price is blind to the market being targeted. Setting a single commodity strike price for a hydrogen producer, irrespective of which market they are serving and which distribution channel is being used, could be highly distorting given the significant cost and value differences between hydrogen markets.

Example: Three very different hydrogen value chains		
Transport	**Industrial**	**Network blending**
High value for a quality product but with higher distribution costs.	Medium value for bespoke customers within a distribution cluster driven by decarbonisation incentives.	Lowest value but also relatively low-cost distribution.
Selling hydrogen into the transport sector, to compete against diesel and petrol, is likely to command a higher price per energy unit, albeit for a higher quality product and a more decentralised distribution system.	Industrial hydrogen producers will be competing against lower cost gas, coke and coal, but with some degree of support from carbon prices and the imperative these industries have to decarbonise.	Blending hydrogen into the gas network may be the lowest cost distribution channel for producers but would deliver the lowest market value, competing against wholesale gas and biomethane alternatives.

Policy makers would therefore need to consider the trade-off between a simple CfD strike price for all producers versus the potential loss of customer demand signals and the market distortions this would cause. There is also a question around whether supply-side subsidies should be targeted solely at producers or also at distribution and storage providers.

A more complex revenue model may be required which differentiates between markets and potentially between different production technologies and distribution channels. A highly bespoke CfD scheme could, however, reduce competition for CfD contracts.

22 There are now some global hydrogen production prices published by Platts, but these are benchmarks and nothing like the level of transparency and granularity available for electricity See Platts www.spglobal.com/platts/en/about-platts/media-center/press-releases/2019/18-12-2019-hydrogen-launch

Maintaining competition and the drive for innovation

A further consideration for policy makers is the extent to which policy interventions might encourage or discourage future value chain development. A well-designed production subsidy would encourage ongoing innovation to reduce costs and carbon emissions, without creating barriers to new entrants or locking into the market inefficient, or high carbon, producers. As an added complication, policy makers will also need to consider the international market for hydrogen to ensure the UK can participate as an import and export partner.

As we have seen in the electricity market, it is not certain that a CfD scheme will encourage innovation and the development of new technologies[23]. A CfD scheme could however be tailored to encourage more innovation by channelling support to less established technologies using allocation 'pots' and technology minima. In the case of hydrogen, for example, this tailored approach could be used to encourage the development of electrolysis technologies which have the greatest long-term potential in terms of cost, energy security and strategic fit with the UK's renewable energy ambition.

A production subsidy could be designed to address the issues of hydrogen market complexity, multiple distribution channels, differential value propositions and the need to ensure continued innovation and technology improvement. But it would be a relatively complex and tailored scheme, perhaps to the point where policy makers are in effect micro-managing the development of the value chain.

An alternative approach – a strong demand-side price signal

A CfD-based approach is attractive to producers, and their investors, as it provides a relatively high degree of revenue certainty. It is, therefore, a supply-side or push subsidy. Aside of the practical issues and risk to competition described already, the inevitable disadvantage of this approach is the dampening of the consumer price signal. An alternative approach would be to look more broadly at a range of policy interventions which would put more emphasis on and focus on nurturing consumer demand-led hydrogen markets.

Most economists[24] and policy makers would probably agree that a mature and sustainable low carbon economy should be based on strong customer value propositions creating demand for low carbon products, underpinned by a universal and effective carbon tax. We are some way off having an effective carbon tax but, if this is the ultimate destination, then a set of policy levers that encourages consumer demand markets based on the inherent value of the greenness of hydrogen would be a step in the right direction.

One potential demand-led approach to support hydrogen would be to build on the use of a **Renewable Gas Guarantees of Origin (RGGOs)** certificate scheme. Guarantees of origin, of which there are several international schemes, are intended to provide a guarantee of provenance for renewable energy consumers to offset their carbon tax and decarbonisation commitments, and a tradeable certificate which would allow green energy producers to capture the intrinsic value of the greenness of their low carbon product.

The use of guarantees of origin has been largely overlooked as a renewable energy policy lever. Trading at around a paltry £0.30 per MWh, the equivalent Renewable Electricity Guarantee of Origin (REGO) scheme has so far failed to add material value to electricity producers and has instead become a byword for greenwashing[25]. The reason for this policy failure is discussed elsewhere, but can be summarised as due to an oversupply of REGOs and poor regulation around the marketing of green energy tariffs.

23 Early CfD rounds have tended to favour relatively established technologies such as fixed offshore wind and biomass conversion. Low auction prices now make it difficult for new technologies to compete in the same CfD allocation rounds, an issue which is now being addressed with new pot allocations for less established technologies such as floating wind.

24 https://clcouncil.org/economists-statement

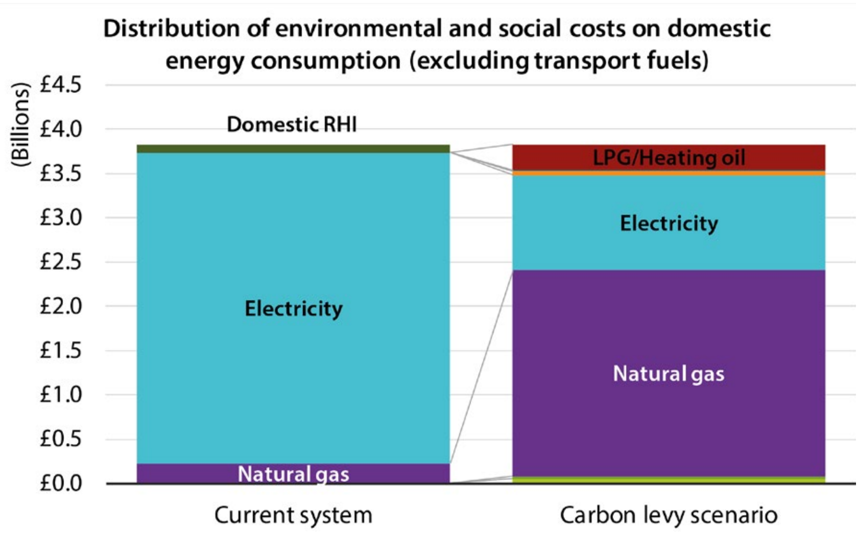
25 We need to talk about green energy tariffs www.regen.co.uk/we-need-to-talk-about-green-energy-tariffs

Green gas is, however, starting from a different place with a current high level of demand for green gas products and a relatively low level of supply (mainly from biomethane). There is also far less secondary, or paper trading, of RGGO certificates.

If managed properly, a RGGO-based approach, combined with an increasing carbon price, could provide a very powerful policy lever to create a route to market and additional value stream for green gas products. Consumers could be encouraged, or regulated, to provide RGGOs (and REGOs) to offset against their carbon tax and decarbonisation commitments. For example, larger industrial users would be encouraged to declare RGGOs as part of the UK Emissions Trading System (UKETS) and as an offset against their Carbon Emissions Tax. This would create a strong consumer-led pull for green gas products and a demand for RGGOs certificates.

Producers of green gas would then be able to trade their RGGOs for a meaningful revenue stream to supplement the commodity value of their energy product. A natural market for RGGOs could be nurtured. Those sectors faced with the highest level of carbon emissions tax would have the greatest incentive to acquire RGGOs and would therefore be willing to pay a higher RGGO price. This would encourage hydrogen producers to focus on the added value of those markets first.

At present, there is no carbon tax paid on domestic heating fuel and, therefore, the incentive for gas suppliers to acquire RGGOs is based only on the domestic consumers' desire to buy green energy. Applying a carbon tax to domestic heating fuels, starting as Regen has recommended[26] with the replacement of the current environmental levies by a carbon levy, would provide a much stronger price signal to support the introduction of hydrogen heating, as well as biomethane and other low carbon heat technologies.



Reconfiguring the current £3.8 billion domestic environmental levies into a carbon levy of circa £36 per tonne of CO_2e results in a decrease in electricity costs of approximately 14% per kWh and an increase in gas of 16% per kWh based on current prices.

Other market approaches could be taken, but a carbon market based RGGO price could provide a more sustainable and technology-neutral support framework for hydrogen producers and consumers. It would ensure that producers remain responsive to consumer-led demand and focus on innovation and cost reduction. It would also enable hydrogen to compete on a level playing field against other low carbon solutions.

The disadvantage of a RGGO approach, from the perspective of encouraging rapid investment in manufacturing capacity, is that it would not provide the same level of production revenue guarantee enjoyed by CfD contract holders. There are several ways in which this could be addressed, such as setting a minimum RGGO price guarantee, or a supplementary subsidy. It would also be possible to combine a demand-led RGGO approach with a complementary production support subsidy, although one which would be less generous and perhaps more time limited, or tapered, than a full CfD.

26 See Decarbonisation of Heat, Regen 2020 www.regen.co.uk/wp-content/uploads/Regen-Heat-Paper-WEB2-Single-Page.pdf

Lots for the industry and policy makers to think about

While the development of a hydrogen value chain offers tremendous potential for UK industry, and could be a critical part of a future low carbon energy system, there are a lot of market elements for policy makers to consider.

The issues and complexities outlined in this paper can certainly be addressed, but the devil will be in the detail. It took several years to develop the current CfD scheme for electricity and arguably the design, or more accurately the implementation, was imperfect.

Getting consensus across the wide range of hydrogen stakeholders and commercial interests, in what is still a relatively young industry, will perhaps be the biggest challenge. Certainly, policy makers need to be mindful not to be captured by incumbent players; the whole hydrogen industry, producers, innovators, customers and the supply chain, will need to be heavily engaged in what happens next.

Author: Johnny Gowdy

Johnny Gowdy is a director at Regen. His 30 years of experience working in energy industry has taken him from the oil and gas sector to renewable energy and decarbonisation. His oil and gas experience was gained in supply chain consultancy where he supported clients in oil production, and the development of the hydrocarbon supply chains covering the manufacturing (refining), supply and distribution of oil products.

Regen is a not-for-profit centre of energy expertise and market insight whose mission is to transform the UK's energy system for a net zero carbon future.

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This insight paper is part of a series that Regen has produced to explore the role that hydrogen could play in a future net zero energy system. Future planned papers and short blogs will look at:

- Hydrogen costs and the potential for radical cost reduction
- Hydrogen for industry and how it could help meet the most difficult decarbonisation challenges
- Hydrogen in the energy system: how hydrogen could become a key storage and cross-vector fuel helping to balance and provide security supply in a renewable energy system
- Hydrogen heating: exploring the potential for hydrogen to play a significant role as a heating fuel and considering what form that might take

The Decade to make a difference series

The UK's commitment to net zero carbon requires a transformation in the way in which energy is generated, distributed and consumed. As a key enabler of decarbonisation, the energy industry is being asked to rise to the decarbonisation challenge and will need to achieve rapid and dramatic change. The big question is whether the industry, working with its stakeholders, will be able to do this? And if so, what new technologies, policies and business models will be required to enable radical change?

Throughout 2020 Regen will be publishing a series of thought-provoking papers looking at the challenges and solutions that would deliver transformation change across the industry. These will cover the themes of renewable electricity, decarbonisation of heat, low carbon transport, energy efficiency, and the role of cities and regions to reach net zero carbon.

This discussion paper has been researched and produced by Regen, an independent not-for-profit organisation that is committed to the transformation of the UK's energy system. Regen would like to thank our members, and the wide range of industry stakeholders that have provided their expertise and insight to help us develop our thinking. We would also like to thank Wales & West Utilities for supporting the production of this paper. All opinions and views expressed in the paper are Regen's, unless explicitly referenced. We would welcome feedback and comments, and encourage readers to continue to engage with us through our events and membership.