Department for Energy Security & Net Zero

HYDROGEN PRODUCTION DELIVERY ROADMAP

December 2023

Any enquiries regarding this publication should be sent to us at: hydrogenhub@energysecurity.gov.uk

Contents

Executive Summary

In the two and a half years since the publication of the UK Hydrogen Strategy we have made rapid progress and are now firmly in delivery mode, supporting projects to move us closer to our hydrogen ambitions. We have announced the first round of successful projects under the electrolytic Hydrogen Allocation Round (HAR1) worth 125MW, in addition to the 34MW through round 1 of strand 2 of the Net Zero Hydrogen Fund (NZHF). The second Hydrogen Allocation Round (HAR2), which is over three times the size of HAR1, is now underway, and the contracts from round two of the NZHF strands 1 and 2 will be announced in the new year.

This progress has been possible due to the UK's strong policy framework for growing hydrogen production – including our Hydrogen Production Business Model, Low Carbon Hydrogen Agreement and our Low Carbon Hydrogen Standard. Together this has proved an investable model which has leveraged private investment to kick start the UK's hydrogen economy.

It is our ambition to have up to 10GW of low carbon hydrogen production capacity by 2030, subject to affordability and value for money, with at least half of this coming from electrolytic hydrogen. In addition to this, our near-term aim is to have up to 1GW of electrolytic hydrogen and up to 1GW of carbon capture, usage, and storage (CCUS) enabled hydrogen in construction or operation by 2025.

For the next stage of growth, we need to make sure the right conditions are in place as we continue to nurture this nascent market and push towards our 2030 ambition. We will continue our engagement with stakeholders to make sure our policies are developing alongside industry need.

This Hydrogen Production Delivery Roadmap sets out our vision for hydrogen production to 2035, with ambitions to:

- Allocate up to 4GW of our 2030 ambition to CCUS enabled hydrogen through CCUS allocation rounds for Track-1, Track-1 expansion and Track-2, subject to project assessment, cluster assessment and successful negotiations with projects.

- Allocate up to 6GW of our 2030 ambition to electrolytic production, with alternative technologies also contributing towards this total.

- Run annual allocation rounds for electrolytic projects, and potentially alternative technologies, between 2025-2030.

- Allocate up to 875MW in HAR2.

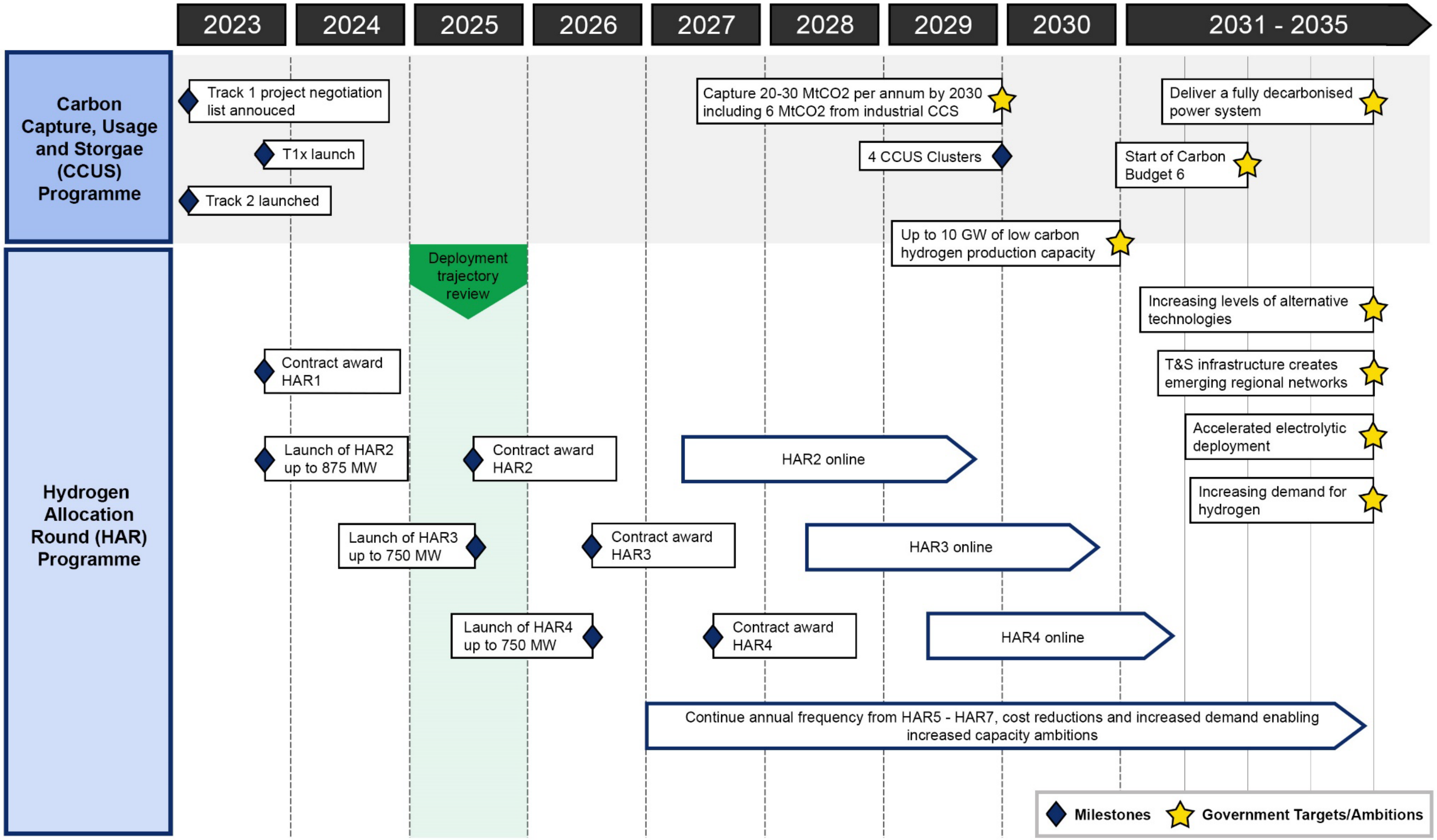
- Allocate up to 1.5GW across both HAR3 and HAR4 which are expected to launch in 2025 and 2026 respectively.

- Review our deployment trajectory in 2025 in light of learnings from early projects, the evolving evidence base and strategic decisions on the use of hydrogen, taking into consideration emerging evidence on cost reductions, innovation, infrastructure requirements and demand-side developments.

Achieving this ambitious deployment trajectory will be subject to affordability and value for money, and we will look to industry to rise to the challenge of demonstrating significant cost reductions as the UK hydrogen sector takes off. Key to this, will be working with demand sectors to maximise this opportunity and develop a competitive marketplace that can drive investment and push costs down as we establish our hydrogen transport and storage infrastructure. Our hydrogen ambitions can drive investment into the UK and help ensure fair opportunities for UK companies in the supply chain and our skills base, as well as wider economic benefits to all regions of the country.

As the hydrogen production landscape develops, we expect to see CCUS enabled hydrogen supporting decarbonisation in the industrial clusters, and increasingly large electrolytic projects sited in locations that allow us to take advantage of the deployment of renewable electricity generation. Transport and storage (T&S) infrastructure will be needed to connect and balance this production with demand. We are publishing a Hydrogen T&S Networks Pathway alongside this Roadmap that identifies supporting emerging regional networks centred on availability of storage and credible regional production and demand as the priority for early T&S infrastructure. In support of increased hydrogen production, we will continue to deliver our business models, policies on transport and storage, regulation, standards and certification, sector development and demand, as set out elsewhere in this Roadmap and accompanying publications.

Hydrogen Production Delivery Roadmap



Introduction

The "Mission Zero" Independent Review of Net Zero, led by Chris Skidmore, set the recommendation that "by the end of 2023, the Government should develop and implement an ambitious and pragmatic '10 year' delivery Roadmap for the scaling up of hydrogen production."

In response to this recommendation, we are publishing this Roadmap to set out how we expect the hydrogen production landscape to evolve towards 2035, and the key opportunities and challenges that we will face. On the pathway to delivering our 2030 ambition we will need to adopt a flexible approach that is sensitive to emerging evidence and allows us to be agile as hydrogen demand increases. We will therefore review our trajectory in 2025 to ensure it continues to reflect the rapidly developing market for low carbon hydrogen.

Since the publication of the UK Hydrogen Strategy in 2021 we have supported a range of low carbon hydrogen projects:

• We have announced 15 successful applicants from round 1 of the NZHF strands 1 and 2 who have received a total of £37.9 million support.

• We plan to publish a list of further successful projects from round two of the NZHF strands 1 and 2 in early 2024.

• We have announced the first successful projects from HAR1

• We are in negotiations with two CCUS enabled projects: H2Teesside and HyNet Hydrogen Production Plant 1.

In just a few short years we have laid the foundations of our hydrogen economy. We have developed a world leading Low Carbon Hydrogen Standard, providing us with a robust methodology to measure the carbon intensity of hydrogen, ensuring that the hydrogen we support is genuinely low carbon and is contributing to our net zero goals. We have also developed the Hydrogen Production Business Model (HPBM), giving us a means of providing revenue support to projects, and the Net Zero Hydrogen Fund, supporting early projects to bring forward hydrogen production at scale. We have also launched allocation processes for both electrolytic and CCUS enabled hydrogen production projects.

The first hydrogen allocation round (HAR1) launched in July 2022, offering both NZHF capital and HPBM revenue to support electrolytic projects. A total of 11 projects were successful through this process, totalling 125MW, with first projects becoming operational in 2025. Building on the success of HAR1, we have now launched HAR2 to award contracts for up to 875MW of projects (subject to affordability and value for money) to continue to support our aim of 1GW of electrolytic hydrogen in construction or operation by 2025. Following the selection of HyNet and the East Coast Cluster as Track-1 CCUS clusters in November 2021, and the publication of the March 2023 CCUS Track-1 Project Negotiation List, we are currently negotiating with two large scale CCUS enabled hydrogen production projects, H2Teesside and HyNet Hydrogen Production Plant 1. This document sets out a number of case studies showcasing some of the projects that are under development.

Over the last 6 months we have been regularly engaging with industry through the Hydrogen Delivery Council[1] Production Working Group. We thank the Working Group for their time and have taken the outputs of this group into consideration when developing this Roadmap. In particular, we recognise some of the key messages coming out of this group:

• The active role that government will need to play in supporting the development of the hydrogen sector.

• The need to build investor confidence and develop early learnings by delivering our 'first of a kind' projects at pace.

• The key enabling role that hydrogen transport and storage can play in growing the hydrogen economy.

• The need for greater future certainty on both the volumes of hydrogen government is seeking to support, and the timelines for funding rounds and processes, to allow for better project planning right across the value chain.

This Roadmap, alongside the other documents published in this package, sets the foundations for delivering on these key messages. We will continue to work together with the Hydrogen Delivery Council Production Working Group and other stakeholders to deliver on the commitments set out in this Roadmap.

Whilst we have made significant progress since the launch of the UK Hydrogen Strategy in 2021, the industry is still nascent and there are a number of variables that will shape what the hydrogen economy will look like in 2035. For example, the scale and location of hydrogen demand will be impacted by government-led decisions such as the decision on hydrogen for heat in 2026, individual business level decisions on what decarbonisation pathway is most appropriate for them, and the availability of hydrogen infrastructure. Instead of trying to over-design a growing market, we continue to focus on getting the near-term actions right to enable us to move into the next phase, while providing confidence to industry and investors in the enduring funding regime for early projects and government's long-term vision for a thriving hydrogen economy.

We must now also focus on building hydrogen transport and storage infrastructure, increasing our understanding of end use sectors, developing a range of deployable low carbon hydrogen technologies to give us optionality, and delivering a steady stream of commercially scaled hydrogen projects that we can learn from to bring down costs. All of this combined will be essential to allow us to allocate at much greater volumes later this decade.

[1] https://www.gov.uk/government/groups/hydrogen-delivery-council#membership

Case study 1 - The Knockshinnoch Green Hydrogen Hub Project

We are supporting the Knockshinnoch Green Hydrogen Hub Project (KGH2P) through NZHF grant funding, to deliver one of the first fully off-grid renewable hydrogen supply systems in the UK.

Situated in East Ayrshire, Scotland, the project will see wind turbines installed alongside a battery that will be directly connected to an electrolyser to produce fuel-cell grade hydrogen. The compressed hydrogen is expected to be stored on site before being transferred to mobile trailers to power transport, as well as other hydrogen applications.

The project, expected to be operational in 2025, will enable the commercial deployment of hydrogen to the transport sector, supplying over 160 tonnes of low-carbon hydrogen per year to the sector. This will contribute to the reduction of the UK's transport emissions by laying the hydrogen supply foundations for the country's ever-growing zero-emission bus and truck fleets.

Our Hydrogen Ambition

The British Energy Security Strategy, published in April 2022, highlighted the critical role that low carbon hydrogen will play in our energy system, supporting both UK energy independence and our carbon reduction targets. As part of this strategy, we doubled the UK's ambition to up to 10GW of low carbon hydrogen production capacity by 2030, subject to affordability and value for money, with at least half of this coming from electrolytic hydrogen. In addition to this, our near-term aim is to have up to 1GW of electrolytic hydrogen and up to 1GW of carbon capture, usage, and storage (CCUS)-enabled hydrogen operational or in construction by 2025.

This ambition brings with it significant potential for investment into the UK, opportunities for UK companies in the supply chain and our skills base, and wider economic benefits to all regions of the country. In July 2022 we published a Hydrogen Sector Development Action Plan, outlining our approach to seizing the economic opportunities of the developing UK hydrogen sector and continue to work with industry to implement the actions set out in this plan. We are also working with Hydrogen UK to develop a Hydrogen Supply Chain Strategy to identify high value opportunities and areas of future potential in the UK supply chain. In addition, announced in November 2023, Green Industries Growth Accelerator (GIGA) is a £960 million package which will bolster UK manufacturing capacity and strengthen supply chains in high opportunity sectors like low carbon hydrogen, CCUS, electricity networks, nuclear and offshore wind. The next step is to work with industry to carry out market engagement and develop an appropriate delivery mechanism that will maximise the economic opportunity for the UK.

Delivering our ambition and developing a world class hydrogen economy for the UK is a fundamental shift in how we provide clean energy to a range of end use sectors, complementing widespread electrification with the introduction of a whole new energy vector. This presents a huge opportunity for the UK, in terms of both economic growth and decarbonisation, but if the level of domestic production is to accelerate towards 2030 at the rate we need, costs must come down.

Just over 18 months after scaling up our 2030 ambition we have seen signals from industry and investors to say they are up to the challenge. Having already announced 15 successful applicants from the first round of the NZHF strands 1 and 2, totalling £37.9 million support[2], we have announced a list of further successful projects, 125MW of capacity through HAR1 and shortlisted a range of projects from Track-1 of the cluster sequencing process. However, there is much more to do to prepare ourselves for greater levels of deployment.

To this end, within this Roadmap we are setting out ambitious capacity targets of up to 1.5GW across HARs 3 and 4 and setting out our ambition for our first 'up to 10GW of low carbon hydrogen capacity' to come from 6GW[3] of electrolytic and 4GW of CCUS enabled hydrogen[4]. By getting the early foundations right we will be able to leverage these early learnings to accelerate our progress towards up to 10GW of production capacity, putting us in a strong position to meet domestic demand in 2035 with domestic production.

Case study 2 - Felixstowe

Scottish Power and Hutchinson Ports are planning to develop a large-scale green hydrogen production facility at the Port of Felixstowe, aiming to deploy 100MW of electrolytic hydrogen production by 2027. The project's front-end engineering study is being partially funded via the NZHF.

Felixstowe is the UK's busiest port facility and sits within Freeport East. Hutchison Ports will benefit from the carbon free fuel which will provide the means to fuel-switch machinery, including terminal tractors, cranes and rail shunters and will be used in on-site vehicles.

The development opens up new opportunities for surrounding industries to decarbonise their operations, fulfilling local demand for hydrogen liquefaction and ammonia production. This project provides an optimal location for future refuelling facilities for road hauliers and rail freight operators, with an ability to respond to growing demand.

[2] https://www.gov.uk/government/publications/net-zero-hydrogen-fund-strands-1-and-2-successful-applicants
[3] This 6GW is expected to mostly encompass electrolytic technologies with some alternative technology capacity.
[4] This continues to be subject to value for money and affordability

Meeting Hydrogen Demand in 2030 and 2035

As set out in the Hydrogen Transport and Storage Networks Pathway document published alongside this Roadmap, low carbon hydrogen is a leading option to decarbonise industrial processes that are harder or more expensive to electrify, and can provide cleaner, homegrown energy for power, transport, and potentially heating. It will play a vital role in enabling these sectors to contribute to our aim to have slashed emissions by 78% by 2035 in line with Carbon Budget 6, decarbonise the UK power system by 2035, subject to security of supply, and keep us on track towards delivering our legally binding target of net zero greenhouse gas emissions by 2050. However, our understanding of the exact scale of hydrogen demand that will come forward across these sectors continues to evolve.

Chapter 2 of the Hydrogen Transport and Storage Networks Pathway sets out our current understanding of where, when, and for what purposes early demand for hydrogen is likely to materialise and provides potential ranges for hydrogen demand across key sectors in 2030, 2035 and 2050, shown in Figure 1[5].

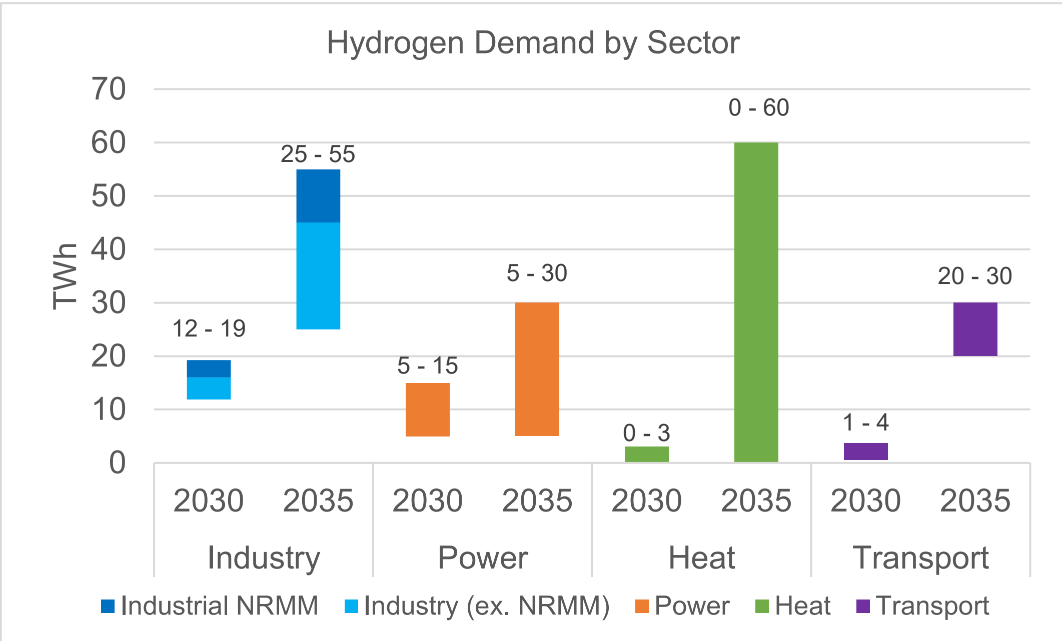


Figure 1 - Hydrogen Demand by Sector

[5] The analytical annex to the Hydrogen Transport and Storage Networks Pathway, published alongside this document provides detail on the evidence sources and methodology informing these ranges. They are intended to illustrate the potential scale of demand in each sector, but do not represent specific sectoral demand targets or policy positions.

We need to plan our hydrogen production capacity to meet the needs of the hydrogen economy. Our first 10GW of capacity could produce around 60TWh/yr of low carbon hydrogen, providing around 10 MtCO2e/yr carbon savings, once fully operational. This assumes we deploy 4GW of CCUS enabled hydrogen and 6GW of electrolytic hydrogen operating at load factors of 95% and 50% respectively[6]. If demand for hydrogen in industry, power, heat and transport was at the top end of the estimated ranges shown in Figure 1, we could need up to 40 TWh of hydrogen supply in 2030 to meet this demand domestically.

Figure 1 also shows that, as we move towards 2035, we expect demand for hydrogen to increase sharply. We need production to be ready to meet this demand, so to support this and balance supply and demand there are a range of measures we can use.

Both hydrogen transport and storage (T&S), and hydrogen blending could help us match supply to demand. In the Hydrogen Transport and Storage Networks Pathway, we set out clear objectives to guide strategic planning of T&S infrastructure to ensure it can support our hydrogen ambitions. Having the right T&S in place at the right time will support decarbonisation, enable the growth of the hydrogen economy and unlock whole system benefits across energy, the economy and the environment.

T&S infrastructure networks can connect producers to a wide pool of offtakers and provide access to the storage necessary to manage imbalances between supply and demand. Larger networks can support ‘security of demand’ for producers, just as they increase security of supply for users, by connecting multiple sources of supply and demand. Additionally, networks can increase locational optionality for prospective production projects. A greater freedom in choice of location allows considerations such as water availability and electricity network impacts to be prioritised over proximity to demand.

As announced alongside this Roadmap, Government sees strategic and economic value in supporting blending into the GB gas distribution networks under certain situations. Subject to the outcome of the safety assessment and final decision on whether to enable hydrogen blending, there may be a role for blending to act as a reserve offtake, supporting the growth of the hydrogen economy whilst ensuring it does not ‘crowd out’ the supply of hydrogen to alternative end users who require it to decarbonise. Additionally, it may allow us to build electrolysers ahead of demand or enable the development of hydrogen transportation and storage, in locations that can benefit the wider energy system, for example in locations where there is an oversupply of renewables, leading to network curtailment.

Trade of hydrogen could help balance domestic production and demand. Exports could help increase the overall low carbon hydrogen production capacity in the UK and address potential

[6] Load factors for electrolysers are highly uncertain and will vary for each individual project depending on a range of factors including their electricity source, the needs of their offtakers, and their access to storage. 50% is an illustrative assumption that reflects the potential for electrolysers to operate flexibly, running at times of high renewable supply and turning off at times of high electricity demand/low renewable supply. Average load factors could be higher or lower than this, which would affect the volume of hydrogen produced by the 10 GW ambition.

demand uncertainties. Imports on the other hand could play a longer-term role in building energy supply resilience and meeting increased demand.

Given the rapidly evolving landscape, we must adopt a flexible approach that is sensitive to emerging evidence on demand and allows us to be agile in our response. This will require government to conduct regular reviews into whether our current trajectory is suitable for our future needs, starting in 2025. We can lay the foundations of a successful hydrogen economy now, giving ourselves the tools to meet the challenge of steeply increasing demand as we move towards 2035.

Allocation process for electrolytic and CCUS-enabled hydrogen production to 2030

In the July 2022 Hydrogen Strategy Update to the Market we set out our ‘twin track approach’ to support multiple hydrogen production routes through our funding mechanisms, provided that projects can meet the LCHS and wider eligibility requirements. As we move forward, we continue to recognise the need to support multiple different production technologies through a range of funding mechanisms. In this section we set out our ambitions for CCUS enabled hydrogen and details of how we expect the Hydrogen Allocation Rounds process to run.

CCUS Enabled Hydrogen

Analysis by both DESNZ and the Climate Change Committee has indicated that low carbon hydrogen from natural gas with Carbon Capture, Usage and Storage (CCUS) – or ‘blue’ hydrogen – will be important in scaling up production into the 2030s and can be consistent with our net zero commitments. CCUS-enabled hydrogen plants currently offer the largest individual production capacities of any projects in the current UK pipeline, with the ability to produce hydrogen at consistent baseload from the mid-2020s onwards.

To support this technology, we have made significant progress with our CCUS program, and are taking forward the development of four CCUS clusters, Hynet (North West England and Wales), East Coast Cluster (Teesside and Humber), Acorn (North East Scotland) and Viking CCS (Humber).

In March 2023, we published the Track-1 Project Negotiation List of 8 projects, which we have selected through the Cluster Sequencing Process to progress to negotiations. This will form the first two CCUS clusters, based in HyNet and the East Coast Cluster. This includes two CCUS-enabled hydrogen projects – H2Teesside and Hynet Production Plant 1 – and we are now in negotiations with these and other projects representing a significant step towards the

UK's first operational CCUS networks, delivering first of a kind carbon capture projects in the UK and underlining the government's commitment to delivering our net zero targets. Our ambition remains to take Final Investment Decisions in 2024.

In July 2023, government confirmed that Acorn (St Fergus, Scotland) & Viking (Humber, England) transport and storage (T&S) systems were best placed to deliver Track-2 objectives, at this stage, subject to final decisions, due diligence, consenting, subsidy control, affordability and value for money assessments.

It is our ambition to allocate up to 4GW of CCUS enabled hydrogen through CCUS allocation rounds for Track-1, Track-1 expansion and Track-2, subject to project assessment, cluster assessment and successful negotiations with projects.

In the longer term, as set out in the Net Zero Strategy, up to 20% of hydrogen supply in 2050 could come from hydrogen BECCS, providing not only a valuable route to decarbonising multiple end-use sectors, but also delivering negative emissions in support of our carbon budgets and net zero. To support the scale up of this technology we encourage eligible BECCS projects that have access to the CCUS networks to add CCS and apply for support via the Cluster Sequencing process. Where biomass-hydrogen projects cannot add CCS, they may be eligible for support under HAR2.

To further contribute to our ambition of capturing and storing 20-30 $MtCO_2$ per year, we will continue to develop the Track-1 clusters to increase the benefits they can deliver. We intend to launch a process shortly to begin further expansion of Track-1 clusters, beyond the initial deployment, identifying and selecting projects to fill the available storage and network capacity anticipated to be available in and around 2030.

Electrolytic Hydrogen

Due to the benefits it offers to the electricity system, energy security and decarbonisation, electrolytic hydrogen is likely to be a core long-term hydrogen production technology. It is expected to be able to operate flexibly, responding to the availability of electricity inputs, and when paired with renewable electricity can deliver zero carbon hydrogen.

Electrolytic – or 'green' – hydrogen also provides a method for utilising otherwise wasted 'curtailed' electricity, which results from having more low carbon generation than we can use at that point in time. As we scale up deployment of renewables, we expect that increasing levels of this excess electricity generation can be used to produce hydrogen. Excess electricity generation is a challenge for the Electricity System Operator (ESO), as managing network constraints involves paying generators to turn-down (curtail) in locations where the network is constrained and paying generators to turn-up closer to electricity users. This is costly for electricity consumers and increases emissions. National Grid ESO analysis indicates that, if delays to network build persist[7], annual constraint costs could rise from around £2bn[8] per year in 2022 to around £8bn[9] per year (£80 per household per year) in the late 2020s.[10] Electrolysers could help alleviate network constraints by locating behind network constraints and utilising the generation that would have otherwise been curtailed due to the constraint.

In order to kick start our electrolytic capabilities we have provided support through the first Hydrogen Allocation Round (HAR1), announcing that contracts will be awarded to projects with a total capacity of 125MW.

Hydrogen Allocation Round 2

In May this year, we published a market engagement document, setting out our proposed approach to the second Hydrogen Allocation Round (HAR2) process for low carbon electrolytic and non-CCUS enabled hydrogen projects. Building on the success of HAR1, we have launched HAR2 with a revised aim to award contracts for up to 875MW of capacity in 2025, subject to affordability and value for money, in order to reflect our continued commitment to deliver our ambition to have up to 1GW of electrolytic hydrogen operational or in construction by 2025. We have now published our response to this market engagement alongside application guidance for HAR2 and have launched the application window which will run from 14 December 2023 to 19 April 2024.

Schedule for future HAR rounds from 2025-2030

In the British Energy Security Strategy, government set out ambitions to hold annual hydrogen allocation rounds for the Hydrogen Production Business Model (HPBM), and for the first two rounds to deliver up to 1GW of electrolytic hydrogen in construction or operational by 2025. We intend to increase the ambition for the following two allocation rounds with an aim to deliver up to 1.5GW.

To increase certainty to industry, we intend to move to annual allocation rounds for the HPBM from 2025 (i.e. from HAR3) for electrolytic, and potentially other alternative technologies. We understand, through lessons learned on the Contracts for Difference regime and our engagement with industry, that it is essential to establish a predictable schedule of allocation rounds that will provide industry with the certainty necessary to bring forward long-term investment into low carbon hydrogen. This will also support our wider ambitions for driving investment into the UK and help ensure fair opportunities for UK companies in the supply chain and our skills base. The table below sets out when we intend to launch future allocation rounds and subsequently award contracts out to 2030, subject to affordability, value for money, market conditions and deliverability.

[7] FTI Consulting (2022), Updated modelling results, slide 12, https://www.ofgem.gov.uk/sites/default/files/2022-11/Workshop%20Slides%2020th%20October.pdf
[8] National Grid ESO, Monthly Balancing Services Summary (MBSS), 2022, https://www.nationalgrideso.com/data-portal/mbss
[9] Undiscounted, 2022/23 prices.
[10] The Department for Energy Security & Net Zero commissioned National Grid ESO to estimate constraint costs with a 3-year delay to network build. Limitations of this analysis are set out in the ‘Risks and assumptions’ section.

For HAR2, we are introducing the concept of delivery years as we move away from Commercial Operational Dates (COD). With this approach, in order to meet HAR2 eligibility criteria, projects will need to demonstrate that they are able to be operational within one of three delivery years, between 31 March 2026 and 31 March 2029. We are minded to apply the same structure for HAR3 and HAR4 rounds, as set out in the below table, offering flexibility for projects given supply chain issues, grid connection delays as well as enabling larger more ambitious projects to apply into the HARs.

Alongside certainty on timing of the allocation rounds, we recognise that forward sight on the expected capacity targets of these allocation rounds will also be of importance, not just to developers but also for investors and the broader supply chain. The table below sets out our capacity ambitions for HARs 2, 3 and 4.

We have already signalled our intention to allocate up to 875MW of low carbon hydrogen capacity through HAR2, and through HARs 3 and 4 we intend to allocate up to 1.5GW[11] of low carbon hydrogen capacity across both rounds, subject to affordability and value for money. Should these rounds attract sufficient deliverable, high-quality and affordable projects that meet our strategic objectives we will consider increasing the capacity ambitions.

	HAR 2	HAR 3	HAR 4	HAR 5	HAR 6	HAR 7
HAR launch	2023	2025	2026	2027	2028	2029
Contract Award	2025	2026	2027	2028	2029	2030
Capacity target	Up to 875MW	Up to 750 MW	Up to 750 MW	TBA	TBA	TBA
Delivery Years	31/03/2026 – 31/03/2029	31/03/2027 – 31/03/2030	31/03/2028 – 31/03/2031	TBA	TBA	TBA

As set out earlier in this Roadmap, Government will need to review the deployment trajectory beyond HAR4 in 2025, based on emerging evidence and strategic decisions as we accelerate towards 2030. The capacity targets for HARs 5-7 will be informed by this review and will be determined by factors such as the emerging evidence on demand, affordability, and our experiences of the preceding allocation rounds, as well as strategic decisions on the use of hydrogen across sectors.

As the hydrogen market develops, we expect to see a range of technologies, as well as larger electrolytic projects (e.g. over 1GW) coming through the pipeline. Bringing forward large-scale

[11] Government reserves the right to revise capacity ambitions ahead and during each allocation round in line with affordability and value for money.

electrolytic projects will be key to ramping up our hydrogen production capacity, achieving economies of scale and wider supply chain benefits, although it will be important that these large-scale projects are located and/or configured to minimise impacts on the electricity network and linked to suitable hydrogen transport and storage networks. We welcome the work that is already being progressed on large-scale electrolysis, and would encourage projects of this scale to come forward and discuss them directly with DESNZ.

Transitioning to price-based competitive allocation

For HAR2, we have published the Application Guidance document that sets out the finalised details of HAR2. Beyond HAR2, to inform the move to price-based competitive allocation, we launched a Call for Evidence on the future policy framework for allocation of the HPBM for electrolytic and other non-CCUS technologies in May 2023.[12]

The majority of respondents to our Call for Evidence were in support of the primary objectives – cost reductions and deployment at scale – underpinning future hydrogen allocation rounds. However, respondents were concerned that it was too early to focus primarily on cost reductions in 2025, and that learnings from early operational projects, as well as development of hydrogen transport and storage infrastructure, would be needed prior to moving to price-based competition. Respondents were concerned that moving to such a model too early could result in underbidding and significant rates of non-realisation, if project deliverability was not fully assessed. For further information, we have published a summary of responses to the Call for Evidence alongside this document.

We have considered this evidence in the context of the DESNZ hydrogen production pipeline, lessons learned from HAR1, and the international context to inform how we develop the allocation rounds beyond HAR2. Our view is that an incremental approach to moving towards price-based competition is most appropriate. As we transition to price-based competition, we will continue to focus on deliverability of projects and ensure that the portfolio of projects selected are value for money and deliver to our wider strategic objectives, such as electricity systems benefits.

Therefore, we propose:

- For HAR3 and HAR4 to be DESNZ-led. DESNZ will remain responsible for the development and delivery of these allocation rounds. This will allow government to drive competition whilst ensuring that successful projects are deliverable and represent value for money by considering costs alongside other strategic objectives.

- Continuing to assess electricity system benefits as well as economic benefits and supply chain development. Whilst we will gradually increase our focus on cost reductions, this will be balanced with support for the broader outcomes of 'harnessing electricity system benefits' and

[12] https://www.gov.uk/government/calls-for-evidence/price-based-competitive-allocation-for-low-carbon-hydrogen-call-for-evidence

‘economic benefits and supply chain development’ set out for HAR2. These broader outcomes will continue to be important to government, and it is our intention to continue to incentivise these through the allocation rounds. In line with Call for Evidence responses, we will review our approach to assessing ‘harnessing electricity system benefits’ as broader policies such as Review of Electricity Market Arrangements (REMA) develop to ensure alignment and to mitigate distortions.

• For HAR3 to be similar in design to HAR2, but with an increased focus on costs. We will look to further streamline the allocation process, building on lessons learned to shorten the time between application and award. Following a shortlisting process, we are planning for the ‘agreeing an offer’ stage[13] to continue to include engagement with government and an element of bidding, with the latter likely to play a more central role. We will look to introduce levers to incentivise applicants who have been successful in the allocation process to sign the HPBM offered to them and to minimise the risk that those who enter into a HPBM fail to deliver the project.

We will aim to publish a Market Engagement document ahead of HAR3 to test this and other design issues further.

• For HAR4, it is our intention for the ‘agreeing an offer’ stage to be more price competitive, and more focused on a mechanistic bidding process rather than bilateral negotiations. As the hydrogen market develops, we expect projects entering into the allocation process to be more mature at the application stage. We will look to further streamline the whole assessment process. We will consider whether additional due diligence and negotiations may be necessary for larger projects.

We intend to continue our process of engaging with industry on the design of each allocation round prior to its launch to ensure that it reflects the current stage of market development.

• In 2025 we will review the design of allocation rounds beyond HAR4. This could include moving to an independent allocation body and auction model from HAR5 at the earliest. When conducting this review, we will take into consideration the relevant market conditions and our experience of earlier rounds. This should give industry appropriate sight before implementing a new delivery model.

Achieving value for money

One of the core principles set out in the UK Hydrogen Strategy was related to minimising disruption and costs, highlighting our focus on ‘learning by doing’ in the 2020s.

Due to the need to kick start the UK’s hydrogen economy this decade, where we currently have less than 5MW of low carbon hydrogen production capacity online, we need to continuously learn from early projects to help minimise costs. This is in terms of both how government allocates support and ensures value for money, and the cost reductions that come

[13] For HAR1 and HAR2, following evaluation and shortlisting shortlisted projects then proceeded to the ‘agreeing an offer’ stage which included project due diligence, a value for money assessment and engagement with government with the aim to agree an offer of support through a LCHA.

from commercialising and normalising new technologies. We will continue to work closely with industry to achieve cost reductions across all parts of the value chain, as part of our wider hydrogen strategy.

The pace needed to grow new low carbon hydrogen production, to help meet our legally binding carbon reduction targets, means we are not able to wait for projects to complete and come online before assessing outcomes and take learnings, like we would for an innovation programme. This will need to be done on a rolling basis throughout the 2020s. But we are already seeing benefits from running the first HAR, with project developers stating that they will be able to reduce costs for the next allocation round. We will therefore reinforce our commitment to cost reductions by setting out a price challenge for HAR2 when publishing the shortlist for the 'agreeing the offer' stage of the process.

Setting ambitions for HAR3 and 4 to deliver up to 1.5GW production capacity gives industry the certainty they need to secure investment and commit to building the projects we need. However, to deliver on these ambitions we will need costs to continue coming down - we are committed to achieving these ambitions but not at any cost. Growing our hydrogen economy must continue to be done in the context of being affordable and delivering value for money across the economy.

This is why we will continue to set stretching price challenges for each allocation round and will review our deployment trajectory beyond HAR4 in 2025, based on emerging evidence and strategic decisions as we accelerate towards 2030. The capacity targets for HARs 5-7 will be informed by this review and will be based on deliverability, cost reduction, affordability and achieving value for money. Our approach for future rounds will also be determined by factors such as emerging evidence on demand, our experiences from the preceding allocation rounds, and strategic decisions on the use of hydrogen across sectors.

Case study 3 - Kintore Hydrogen

We are supporting Statera Energy's Kintore Hydrogen project via the Net Zero Hydrogen Fund (NZHF). The grant is providing help in progressing planning and consenting work as well as the delivery of a front-end engineering design (FEED) for the first 500MW phase of the 3GW project.

Kintore Hydrogen is aiming to utilise excess offshore wind power in Scotland to produce low-carbon, green hydrogen which can be supplied through a network of existing pipelines across the country to decarbonise both power generation facilities and carbon intensive industrial clusters. Upon completion, Kintore Hydrogen will be one of the largest green hydrogen projects in Europe.

Statera estimates the project will save around 1.4 million tonnes of CO_2 annually across UK power generation and industry.

The Northeast of Scotland has historically been a world leader in the energy sector, and large, first-of-its-kind pioneering projects like Kintore Hydrogen will help unlock investment in wind and hydrogen across the region, retaining that leadership, as the UK transitions to a renewables-led energy system. As part of this transition, the project will also create new green jobs and opportunities for the wealth of skilled labour in the area.

Alternative Hydrogen Production Technologies

Technologies other than water electrolysis and CCUS-enabled natural gas reforming could have an important role to play in allowing us to scale up our hydrogen production in the 2030s. But to allow them to make a significant contribution in the 2030s, we need to start developing them now. Previously we have set out our technology neutral approach to hydrogen production, encouraging a range of hydrogen production technologies provided they are able to meet the Low Carbon Hydrogen Standard (LCHS), they fit within our broader hydrogen production strategy, and that we understand the system and environmental impacts.

The LCHS was first published in 2022, setting a clear definition of low carbon hydrogen in the UK. The methodology detailed within this did not just apply to water electrolysis and fossil gas pathways, but pathways with both biomass and waste feedstocks. The inclusion of these technologies provided an emissions calculation methodology and pathway specific factors such as the sustainable use of biomass, and negative emissions calculations.

Since its launch we have continued to keep the standard relevant to emerging technologies, taking stakeholder feedback from the 2021 consultation on the LCHS, and more recently through surveys, in-depth reviews and direct industry engagement. This has led to key updates in the two subsequent versions of the LCHS. For example, Version 2 (published April 2023) introduced a counterfactual accounting methodology for waste fossil feedstocks. This recognises the system-wide emissions benefits, which can come about from diverting wastes into hydrogen production, facilitating compliance with the LCHS and thus reducing barriers to accessing subsidy. Another example comes from Version 3 (published December 2023), which introduces a new eligible production pathway under the LCHS – gas splitting with solid carbon. Other novel hydrogen production pathways can seek to be added to the list of technologies covered by the LCHS by following the process set out in Chapter 4 of the LCHS.

We have also broadened the availability of funding for these technologies through HAR2, with gas splitting producing solid carbon, and gasification of biomass and waste (without CCUS) now being able to apply for support through HAR2. We will need a range of technologies to meet our hydrogen ambitions in 2035 and beyond. By looking to support these technologies now, we can enable them to mature and grow to a point where they can contribute significant capacity.

Imports and Exports

As stated in the December 2023 Update to the Market, we want to play a key role in exporting high grade hydrogen from the UK to other countries. In the longer term, we also recognise the role that imports could play in supporting energy security as part of a diverse supply mix.

This is why we have been taking steps to facilitate the trade of hydrogen, including our commitment to setting up a certification scheme from 2025, based on our Low Carbon Hydrogen Standard. We expect this scheme to evolve to facilitate exports and provide a robust way to assess imports and set out more details on this in the government response to our certification scheme consultation, published in October 2023.

Based on industry intelligence, up to 20GW of potential hydrogen projects have been identified in the UK pipeline, to be online by the 2030s, and exports of hydrogen could help bring part of this potential pipeline of projects forward. Exports could help increase the overall low-carbon hydrogen production capacity in the UK, develop supply chains and skills, bring economic opportunities, and increase the UK's strategic importance as a trusted partner to supply energy to the continent.

Supporting Electricity Network Resilience Through Electrolytic Production

The production of hydrogen to reach our ambitions for 2030 and beyond will require electricity. However, we will seek to minimise any adverse impacts of demand for electricity for hydrogen production on the wider electricity grid. The impact of electricity demand on the electricity network is not only dependent on the volume of electricity needed for hydrogen production; the pace of scale up of new low carbon generation to support hydrogen production, as well as the location, operation and configuration of hydrogen production facilities will also be important.

To manage the impact on the electricity grid as it is decarbonising, the LCHS will continue to be designed to minimise negative electricity impacts and to harness opportunities to provide electricity network benefits.

We will also continue to give consideration to encouraging optimal electricity network operation, configuration, and location through the scoring of future hydrogen allocation rounds. We intend to continue to incentivise projects that use additional sources of electricity in low carbon hydrogen production, as these projects will help to reduce electricity system impacts and may help to bring forward new generation that would not otherwise have been available, or to use excess electricity that would otherwise be wasted.

We expect to also continue to incentivise projects that deliver wider system benefits by locating in a beneficial area for reducing electricity network constraints. Constraints are costly for electricity consumers and increase emissions. Projects that locate behind common network constraints and close to renewable generation can help to reduce these costs and can make efficient use of surplus electricity.

Similarly, the development of the electricity transmission system will need to account for the location of hydrogen projects. This will be delivered through the Centralised Strategic Network Plan (CSNP) and the FSO led Strategic Spatial Energy Plan, as outlined in further detail in the Hydrogen Transport and Storage publication, alongside this Roadmap.

The appropriate level of incentive for projects that provide these electricity system benefits will continue to be assessed ahead of future hydrogen allocation rounds, with consideration given to developments in wider policies such as Review of Electricity Market Arrangements (REMA), as well as our understanding of the UK hydrogen production pipeline and intelligence gathered from engagement with industry.

We expect to set out more details in the summer 2024 Hydrogen Strategy Update to the Market about the certain types of behaviours, configurations and locations that are optimal from an electricity system perspective and our evidence to support this.

Case study 4 -Trecwn Green Energy Hub

Statkraft are developing a 15MW electrolytic hydrogen project on the former Royal Navy Armaments Depot in Trecwn, Pembrokeshire. The Government is partially funding a front-end engineering study for the project via the NZHF, which is expected to be completed by 2024.

The proposal is for the site to have hydrogen electrolysers with approximately four tonnes of hydrogen storage and facilities to refuel the transport industry. The hydrogen facility would be powered by the renewable energy generated onsite (through wind and solar).

It is estimated the plant will generate up to four tonnes of hydrogen a day and support an estimated 160 jobs throughout the complete supply chain across the site’s construction and operation phases, and result in an annual saving of around 18,991 tonnes of CO2 equivalent per year by displacing diesel fuel used in transport.

The project would produce enough green hydrogen per day to run a single fuel cell powered bus for over 40,000 miles, or the equivalent of making 350 journeys from Fishguard to Cardiff, but without the harmful emissions produced by traditional diesel or petrol fuels.

Environmental Factors

The deployment of hydrogen production is expected to have a significant positive net environmental impact as hydrogen use is expected to decarbonise a range of end-use sectors. However, DESNZ must work closely across government and with industry to understand and mitigate all environmental impacts of hydrogen production, such as water requirements and quality considerations, critical mineral requirements, use of chemicals, the atmospheric impacts of hydrogen leakage, and any potential changes in soil, water or air quality.

DESNZ research and policy work feeds into the existing and developing future regulatory regime. All planned hydrogen production projects are legally obligated to have robust integrated environmental assessments in place and to comply with the regulatory regime for environmental issues, such as environmental permitting, water permitting, and air and water quality regulations.

Water requirements and quality

Hydrogen production technologies have varying water demand requirements.[14] Water for hydrogen production can be supplied from various raw water sources, including potable water, groundwater, surface water and seawater. Feedstock water is likely to have higher water quality requirements, for example electrolysis will require high purity ionised water, whereas cooling water is likely to require less treatment. Hydrogen producers will need to consider the amount and source of water to be used in production at an early stage in project design, to ensure security of long-term supply and a robust understanding of local impacts.

Potential environmental impacts of effluent release of treated water will also need to be considered, to manage any impacts on natural water environment and ecosystems. These impacts could occur either through heating in local water courses or releasing small volumes of pollution (i.e. mineral effluent discharge).

Although hydrogen water demand is a relatively small portion of total water demand at a UK level, water availability and quality considerations will have to be assessed at a regional and local level to ensure supply issues do not arise and any environmental impacts are accounted for and properly mitigated. The demand for water for hydrogen production is set in the context of some regional challenges in water supply in the UK, with specific regions forecasting water supply risks out to 2050.

We expect to provide a further update on our emerging understanding of water requirements and quality considerations for hydrogen production in the summer 2024 Hydrogen Strategy update to the market, with more focus on regional variability.

[14] Estimates based on an internal project led by the Climate Services for a Net Zero World consortium and DESNZ provided the following water requirements by hydrogen production technology type (litres/kg of hydrogen); Alkaline Electrolysis: 42.0; PEM Electrolysis: 52.2; Solid Oxide Electrolysis: 12.8; SMR with CCS 20.2.

Critical Minerals

Our hydrogen production ambitions are likely to need significant amounts of critical minerals, especially for Proton Exchange Membrane (PEM) electrolysers, which uses platinum and iridium for cathodes and anodes. As set out in the Critical Minerals Intelligence Centre (CMIC) study these critical minerals have the potential for supply scarcity if mitigation measures are not developed, especially in the context of increased global demand for these minerals. These minerals also have a high concentration in specific geographies, meaning supply chain risks and price volatility risks must be appropriately managed. Government is taking several measures to mitigate these risks, such as through strategic partnerships with key producing nations to diversify and secure supply chains, collaborations with industry, and through the development of supply chain strategies. This includes collaboration with international partners, such as South Africa, Canada and Australia, and via multilateral forums such as the G7 and International Energy Agency. In November 2022 the UK announced the creation of a new Partnership on Minerals for Future Clean Energy Technologies with South Africa to promote increased responsible exploration, production and processing of minerals in South Africa.

Government is also looking at ways to promote recycling and recovery by exploring regulatory interventions to promote the re-use, recycling and recovery of critical minerals. UK Research and Innovation’s £15m Circular Critical Materials Supply Chains (CLIMATES) fund supports innovations in the recycling of rare earth elements, as well as research and development, engagement with international partners and activities to identify and support future skills needed.

Government has also established an independent Task & Finish Group on Critical Minerals Resilience for UK Industry, which works to investigate the critical mineral dependencies and vulnerabilities across UK industry sectors, supporting UK industry to promote resilience and diversity in its supply chain and designing a framework for monitoring and mitigating critical mineral supply risk across UK industry sectors.

Hydrogen producers should continue to work closely with DESNZ and wider government to consider scaling up sustainably, ensuring measures are taken to secure supply for electrolyser components in line with our hydrogen production ambitions.

Air Quality & Fugitive Emissions

We need to continually assess any potential air quality impacts of different hydrogen production methods to ensure we maximise decarbonisation benefits and minimise any negative impacts. We also need to minimise the ‘fugitive’ leakage of hydrogen into the atmosphere, given the potential for hydrogen to be an indirect greenhouse gas due to its interaction with other atmospheric gases.

We are continuing to work closely with Defra, the Environment Agency and wider government to ensure policy making and the development of the future regulatory framework reflects our understanding of the air quality impacts of hydrogen production and fugitive emissions. For example, the Environment Agency recently published guidance on ['Emerging techniques for hydrogen production with carbon capture',] which sets out standards to be implemented via environmental permits on pollutant emissions to air, alongside implementation of leak detection and repair programme to minimise hydrogen leakage. DESNZ is working with the National Physical Laboratory (NPL) to develop the next phase of a project to identify, monitor and quantify fugitive hydrogen from industrial applications. The intent is to develop equipment and processes for point-, room- and area-sized leaks from equipment. The UK Low Carbon Hydrogen Standard also includes a clear framework for hydrogen producers to report on fugitive hydrogen emissions and we have published a Fugitive Emissions Risk Reduction Plan template alongside LCHS Version 3, to provide further detail on how hydrogen producers should be monitoring and reducing fugitive emissions.

Wider Environmental Impacts

As hydrogen production increases in line with our net zero goals, we will continue to monitor and assess any wider environmental impacts. This may include land use requirements, at a time of competing priority uses for land to meet our decarbonisation targets, and impacts of the use of chemicals on the wider environment, including potential impacts from regulatory changes affecting supply of these chemicals, alongside wider environmental issues such as to biodiversity and climate change.

We are continuing to monitor these impacts by working across government and industry. For example, we are working closely with Defra to ensure that hydrogen considerations are factored into land use prioritisation, and we are working closely with regulators to ensure a proportionate approach is taken to the regulation of Per- and Polyfluorinated Substances (PFAs) used in hydrogen production. Hydrogen producers should consider the whole system and take actions to minimise detrimental environmental impacts, in line with regulatory requirements. DESNZ is committed to continuing to assess these wider environmental impacts and to work across government and with industry to ensure these impacts are mitigated.

Next Steps

Following the publication of this Roadmap we will continue to work with industry to build a strong and sustainable hydrogen economy. Additionally, we will continue to work closely with Defra and their arms-length bodies including, the Marine Management Organization, the Environment Agency, Natural England, JNCC and Cefas, to ensure policy making and the development of the future regulatory framework considers their remits and ensures a proportionate approach is taken to hydrogen production consenting processes.

We must build a growing pipeline of high-quality low carbon hydrogen projects that are able to deliver increasingly cost-effective hydrogen whilst driving genuine carbon reductions. The actions outlined in this Roadmap set our direction and will be key to delivering a hydrogen economy that is both world-leading and sustainable.

This publication is available from: www.gov.uk/government/publications/hydrogen-production-delivery-roadmap

If you need a version of this document in a more accessible format, please email alt.formats@energysecurity.gov.uk. Please tell us what format you need. It will help us if you say what assistive technology you use.