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FOCUS ON HYDROGEN: STATE OF THE MARKET 2025

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FOCUS ON HYDROGEN: STATE OF THE MARKET 2025

Much has been said about clean hydrogen and its derivatives over the past 12 months. Often it concerns whether excessive hype of the recent past has been replaced with a new reality. Market conditions are dynamic, and structuring sustainable deals remains a complex exercise. But, amongst the ups, the downs and the volatility, we have seen real progress. In this note, we consider the market trends that will impact pathfinder projects seeking commercial operations before 2030.

The activity of recent years has resulted in price and market discovery data. It has provided know-how on what can, and what probably won't, work over the short to medium term. Most notably, with the recent change of administration in the US, we see the impact of policy on the market. As developers and investors look ahead to the end of the decade and plan their investments accordingly, this early experience is invaluable.

For those first mover projects pursuing commercial operations before 2030, we would expect to see further ups and downs. Clean hydrogen deals and associated market conditions differ greatly between geographies, the types of end user(s) involved and the extent of the value chain between the production "well" and delivery "gate".

Clean hydrogen's contribution to the energy transition is becoming clearer, and 2025 could be a hugely important year: we hope to see incremental growth for deal activity and an increasing number of positive final investment decisions.

Key Issues

Overly ambitious targets have been discredited and replaced with a greater focus on sustainability.

Viable use cases available for offtake over the short to medium term are becoming clearer across sectors. These include fertilizer producers, refineries, the maritime sector, steel production and power.

Green premia are being embraced in some sectors, linked to carbon pricing. But pricing is sensitive in most sectors and matching offtake to the cost of production remains the most critical factor restraining long-term offtake and FIDs.

Subsidy schemes and auctions have created offtake opportunities. Auctions to be launched in 2025 in Europe, Korea and Japan will drive more projects to FIDs.

Policy risk is inherent globally. Not least as most projects are reliant on policy incentives and "compliance-based economics" to succeed. This will remain a risk issue over the foreseeable term and, in particular, we await the full consequences of the change of administration in the US.

Technology, supply chain and construction issues continue, with a wide range of approaches being taken to address them.

Project financing solutions over the next 12 to 24 months will be critical. Therefore, establishing risk allocation which is fit for purpose is essential for more FIDs in 2025.

THE OUTLOOK FOR 2025

What is the clean hydrogen market?

When we refer to hydrogen in this note, we are really referring to hydrogen and its derivative products. The fast-paced, emerging clean hydrogen market is already as diverse as it is dynamic. The reality is that there is not just one market. We are seeing a wide range of different projects looking to deliver on the switch to clean hydrogen. Certain of the dynamics facing an ammonia export project are fundamentally different to the dynamics and pricing challenges facing an 'over the fence' or captive hydrogen project. The issues facing a blue hydrogen project compared with a green hydrogen project are also different. If e-methanol is the end-product, as we are seeing in a number of emerging maritime offtake transactions, there will be the need to secure sources of CO_2 meeting the requirements of EU legislation (being biogenic CO_2 or certain categories of captured CO_2). The various geographies, applicable laws and regulations involved, the different approaches to transporting the molecules from "well" to "gate", and the downstream issues associated with different offtake markets create additional differences.

Domestic production versus imports – differing policy objectives in different markets

Policy and objectives differ regionally between domestic production and import strategies. The European Union, for example, targets 10 million tonnes per annum (**Mtpa**) of domestically produced clean hydrogen and 10 Mtpa of imported clean hydrogen by 2030. The latter will involve the importation of blue or green ammonia from places where costs of production should be cheaper than those achievable within the EU. Some of the imported green or low-carbon ammonia will be used in fertilizer production, as a maritime fuel and, potentially, in the power sector. Large parts of these cargoes will, however, need to be cracked back to hydrogen to serve hydrogen use cases across Europe. This creates a pricing arbitrage position, between the higher EU production costs (which will include any applicable carbon pricing costs), on the one hand, and the additional costs of back cracking and transportation costs, on the other. How this plays out in practice in terms of eventual market share between local production and importation remains to be seen.

Nonetheless, we are seeing both export and domestic production projects advance in parallel, both with their own unique benefits and challenges. This suggests that there is a place for both, over the medium to long term. In the shorter term, we would expect to see pricing data firm up as more projects conclude FEEDs, offtake tenders are finalised and downstream and midstream pricing data for transportation and cracking become clearer.

The emerging cost data – hydrogen, ammonia and ammonia cracked back to hydrogen

Estimates suggest[1] that the average Levelised Cost of Hydrogen (**LCOH**) production in Europe is currently around c.$5-8/kg for clean hydrogen. By comparison, grey hydrogen costs between c.$1-$3/kg to produce based on location and prevailing gas prices. Taking EU production costs as the measure, tightness in the gas market and a range of geopolitical uncertainties, it is no surprise that production costs for grey hydrogen and grey ammonia rose over the course of 2024, and there are expectations that this increase will continue for 2025. In comparing the cost of hydrogen and ammonia, the costs of back cracking ammonia to hydrogen and the associated conversion losses need to be taken into account. Cost data varies in respect of cracking costs at present, but it clearly creates significant cost pressure when seeking to deliver an optimal LCOH.

Based on a range of emerging producer locations designed for export, green ammonia costs are estimated to currently sit between $650-$1000 / mt FOB. Over the past year, data has indicated that places like Canada and Australia may find themselves in the higher end of the spectrum, whereas India and China may be in the lower end. There are other green ammonia production markets emerging and showing real progress, including Oman and Egypt. The price data on blue ammonia is also varied. Over the course of 2024, pricing indices suggest a range between c $600 / tonne FOB and c.$435 / tonne FOB. To reach a demand centre such as Europe, these costs will need to include shipping costs and, if the end use is hydrogen, the costs of back cracking (including conversion losses) will need to be factored in.

A general consensus seems to be forming that blue ammonia and blue hydrogen will be a cheaper product than their green equivalents over the short term. But as the larger green projects come online, there is potential for significant cost reductions between now and 2050, meaning that green may be the cheapest product over the longer term.

Targets and reality: what is the size of the clean hydrogen market by 2030?

In recent years, governments published hugely ambitious targets amounting to 90-180 Mtpa of global clean hydrogen production by 2030, based on assumed trajectories needed to reach net zero by 2050. BloombergNEF (**BNEF**) once estimated that 47 Mtpa of production could be operational by 2030, although it suggested that 16 Mtpa was more likely. As of today, only some 0.2 Mtpa of green hydrogen production, and a similar amount of blue hydrogen, is operational. To give a sense of the scale involved, 16 Mtpa of green hydrogen would require c.80-100 GW of renewable power. A reasonable cost estimate for a new green hydrogen production project with a c.200,000 tonnes per annum capacity may be c.USD 5bn.

Over the past 12 to 18 months, these ambitious targets have been tested by real world challenges, and many have been shown to be overly optimistic. A number of high-profile projects have been mothballed, and we have seen credible developers reduce their targets and ambitions for clean hydrogen. Across the spectrum of energy transition investment this situation is not unique to clean hydrogen. We have seen similar issues impact the global offshore wind market.

The key issue for hydrogen is clearly cost, and the ability to match supply to demand in a commercially viable manner. With these challenges requiring bridging in many parts of the market; the question remains open as to how many Mtpa of clean hydrogen will actually be in production by 2030. But it is equally clear that the size of the demand case remains

[1] All pricing information is based on estimates aggregated from a range of publicly available sources.

significant. As of today, the size of the grey hydrogen market is c.90 Mtpa and growing. On top of this existing demand profile, as the world pursues its carbon reduction goals and implements regulation mandates or encourages the same, new clean hydrogen use cases have and will continue to emerge.

Policy risk and law-making – top of the agenda for any hydrogen investment case

Policy support and the risks of changing policy are prevalent features of any hydrogen transaction. Policy can either make or break any market. We saw the effect of policy to promote the market under the Biden Administration and the Inflation Reduction Act (**IRA**), and, more recently, the chilling effect of policy following the start of President Trump's second presidency and his rapid issuance of executive orders, including the order to freeze allocations of funds under the flagship clean hydrogen subsidy regime under the IRA.

For a number of years, the IRA has had a huge impact on the emerging hydrogen markets, both domestically in the US and internationally. Producers have positioned projects in US to capitalise on the up to $3kg tax credit over 10 years. This generous subsidy has also impacted trade elsewhere. For clean ammonia export projects in other jurisdictions, offtakers have been benchmarking negotiations against pricing that may be obtained from US producers benefiting from IRA support.

Until recently, a key issue for US-based production projects has been the need for clarity on the application of the eligibility rules for receipt of the IRA subsidy. Clarity on these rules has often been quoted as a hindrance to achieving FID. The 45V guidelines were, however, published by the outgoing Biden administration in December 2024. For those US projects looking to achieve FID during 2025, the key focus is now on the policy of the new Administration and the long-term future of the IRA.

This is just one, albeit high-profile, example of changing policy risk in action. Whilst it remains to be seen where the new Administration will go on clean hydrogen, the spectacular change in policy, as President Trump pursues his vision for energy and environment in the US, demonstrates how policy has the potential to make and break a market. We expect that policy volatility globally will continue to be a key risk item for investments over the short to medium term.

Pricing that works for the offtaker

In this market, matching the cost of production with the price an offtaker is willing to pay is subject to two broad categories of issues.

One part of the challenge relates to costs of production and ensuring that a project is truly competitive in the global arena. For a green hydrogen production project, the cost of power may account for over 60% of the overall project costs. Projects in locations with cheap power are likely to be the most cost-competitive producers. Maximising electrolyser load factors is also critical, and accordingly, we are seeing projects emerge in jurisdictions with decarbonised grids or having baseload renewable power in the form of hydro. Similarly, for blue hydrogen, competitively procured gas will give confidence that projects can succeed in the market as a competitive producer – with producers in the US and the Kingdom of Saudi Arabia vying for early market share. Other issues also apply. Local market conditions, including tax regimes and royalties in effect, supply chain and costs of construction, grid reliability, water supply, port infrastructure and hydrogen transportation, can all be significant contributions to the cost make up of a production project. Differences in these other costs among projects can play a role in establishing how competitive a project might be within the range of available offtake markets. They should not be underestimated.

The other part of the pricing dynamic is led by end users. Switching from a product subject to carbon pricing for clean hydrogen or any of its derivatives may achieve savings deriving from carbon pricing and fines, and this therefore a creates a form of "compliance-based economics" and pricing structures. The EU Emissions Trading System (**EU ETS**) and the phasing out of free allowances is an example of this. There are emerging fine regimes deriving from sectoral regulation, such as fines to be imposed on shippers under the FuelEU Maritime Regulation and certain aviation industry participants under the ReFuelEU Aviation Regulation. In theory, these regulatory interventions should make grey hydrogen and grey ammonia obsolete over time.

However, in the shorter term, to the extent there is a gap between the costs of production on the one hand, and the costs that the end user is able to assume (taking account of any carbon pricing avoidance) on the other, subsidies will be needed to bridge the gap.

Emerging viability of use cases – existing use cases and new use cases

Fertilizer accounts for over 70% of the world's ammonia offtake at present. Fertilizer offtakers are therefore in high demand, and over the course of the past year a range of fertilizer offtake agreements for clean ammonia (or heads of terms) have been agreed. However, the data shows that the switch from grey to blue or green hydrogen is subject to downstream price sensitivity challenges – in terms of the extent to which the fertilizer market can absorb and pass on the "green" or "blue" premium. Refineries, as a source of existing grey hydrogen demand, are also highly sought after for long-term offtake agreements. Taking the US as an example, most current hydrogen usage is consumed by petroleum refining. In Europe, refinery tenders have demonstrated one potential model for procuring offtake at scale over the past 12 to 18 months.

For industrial end users and existing use cases seeking to switch from grey to blue or green products, pricing sensitivity is probably the key challenge. But other challenges exist, in parallel. Most current hydrogen and ammonia supplies are derived from local (captive or over the fence production facilities). Switching to a source of offtake from an importer or domestic aggregator requires investment and reliance on downstream infrastructure, including challenges of transportation. Further, many of the "in demand" industrial offtakers are being asked to enter into longer term (10 to 15 year + terms) and more restrictive contracts than they are currently used. For this to work and for industrial offtakers to secure their own approvals for long term offtake, they must be sure of the location and scale of their demand over the long term – which can be challenging for certain parts of industry which are subject to their own uncertainties.

Driven by the EU ETS regime applicable to shippers, and fines deriving from the FuelEU Maritime Regulation, we have seen shipping companies order ships capable of running on ammonia and e-methanol. There is also the potential for use of hydrogen or ammonia in the power sector which has attracted interest in the form of policy planning and tenders for volumes – Korea, Japan, Germany and the UK may well be key markets, and others should follow as data on viability emerges.

Marked by the successful debt financial close of Stegra's green steel project in Sweden, green steel has also emerged as a new source of offtake for clean hydrogen. Hydrogen's role in sustainable aviation fuels is another source of offtake, driven by policy interventions such as the EU ETS regime and the ReFuelEU Aviation Regulation.

A clear need for further subsidy allocations in 2025

Despite the range of policy interventions designed to incentivise end user adoption of low-carbon fuels, subsidies appear to be essential to bridge the gap between the cost of production and the costs which offtakers are willing and able to pay across many parts of the market. More than 10 jurisdictions across the globe were actively implementing subsidy regimes in 2024, and they vary greatly in terms of scope, eligibility (including pricing caps) and the nature of the targeted interventions. They are all new to the market, and so both bidders and procuring bodies are learning what works in real time. We would therefore expect to see changes in the design of subsidy frameworks as the market develops.

Export projects, in particular, which encompass shipping costs and, potentially, the costs of cracking ammonia back to hydrogen, have been awaiting tenders from key demand centres in Europe, Korea and Japan. In 2024, we saw the EU's H2 Global run its first tender for ammonia imports on a pilot scheme basis. The same is true of Korea for its ammonia import model designed to procure blue and/or green ammonia imports for use in its power sector, known as the Clean Hydrogen Production Standard model (**CHPS**)**.** Both procured modest volumes with commencement of supplies scheduled for 2027/28. While these procurement models have the potential for driving a large amount of export production volumes, they need to procure much greater volumes in order to do so, and that, depending upon the model and the amount of subsidy, could require substantial additional funding.

At the end of 2024, Japan launched its long-awaited $20bn clean hydrogen CfD model. This will aim to connect ammonia imports with Japanese offtakers and subsidise the delta between a reference price and the costs of production / supply into Japan. It will target 'hard to abate' industrial sectors and may include ammonia co-firing within the power sector.

We will be watching the ongoing Japanese tender model and the upcoming second rounds of H2 Global (which launched in late February 2025 with a circa EUR 2.5bn to EUR 3bn budget) and CHPS as key indicators of continued progress, or not, of export projects around the globe.

The midstream and downstream – networks, storage, cracking

Hydrogen midstream and downstream infrastructure readiness is another essential issue that needs to be progressed to unlock FIDs. Many projects are reliant on new ports, pipelines and cracking facilities to ensure that the product can reach the market. The midstream – in the form of networks and storage facilities – will help open up new use cases, such as hydrogen usage in the power sector, where hydrogen is produced and stored, thereby using electricity which would otherwise have been curtailed.

The European Hydrogen Backbone initiative plans to build 28,000 km of pipeline by 2030 and 53,000 km by 2040, connecting hydrogen "valleys" (essentially industrial clusters) across the EU. The EU's hydrogen and gas decarbonisation package was adopted in May 2024, introducing a new regulatory framework dedicated to hydrogen infrastructure, which is helping to build investor confidence in the EU's commitment to its long-term hydrogen networks strategy.

Similarly, recent announcements around Germany’s hydrogen core network are helping to unlock investor interest. Germany, which is seen as a key market for production projects across the world, has committed €20 billion to a 10,000 km network, with the first 525 km now under construction. This network will primarily consist of converted natural gas pipelines, making up about 60% of the total length. The aim is to have a 9,040 km network operational by 2032, connecting major hydrogen production sites, industrial centres, storage facilities, power plants and import corridors.

The Netherlands is also nearing completion of the first section of its new national network, Hynetwork, and plans to complete 1,200 km by 2030, with connections to Belgium and Germany. Similar projects are underway across Europe. The UK has been consulting on the best way to support the development of hydrogen storage facilities and networks. The US and other large countries are more focused on regional hubs due to the vast distances involved.

All that said, a new geopolitical situation in Europe potentially requiring more defence spending and the potential for an about-face on hydrogen hubs by the Trump Administration could delay or scuttle some or all of this new infrastructure.

The debt financing solution

With many, many billions of dollars of capex needed between now and 2030, project financing will play a key role in the ongoing progress of the market. Whilst most projects remain focused on project development activities (ranging from FEED studies to agreeing offtake arrangements), a small number of projects targeting completion this side of 2030 have achieved debt financial close and a slightly larger number have commenced or are close to commencing a debt launch. Projects remain at the FOAK stage, and the very different drivers impacting each of them means that debt financing solutions will remain varied and complex over the medium term. With greater debt market engagement in the course of 2025, we expect to see some of the more complicated projects find solutions to risk allocation gaps. We also expect there to be opportunities for those with sufficiently liquid balance sheets and risk appetite to utilise sponsor support in various forms to expedite debt financing solutions for certain projects.

EMERGING USE CASES AND PROJECT STRUCTURES

Local and captive offtake

Having a nearby anchor offtaker provides a clear investability pathway and avoids challenges around lack of infrastructure for transport and storage of hydrogen. These are the key benefits for captive or 'over the fence' projects, which we are seeing progress in many parts of the world including the US, Middle East, the UK and Europe.

The disadvantage of reliance on a nearby, anchor offtaker is that finding alternative offtakers is a challenge if the anchor offtaker ceases to be available for any reason. Heavy reliance on one local source of offtake, while convenient on the practical level, therefore poses offtake risk allocation issues that will need to be addressed.

The UK's hydrogen support model has so far focused on domestic production and domestic supply. It does not have an import or export subsidy scheme or policy, at present. At the end of 2023, the UK awarded subsidies, subject to contract, for its hydrogen production CfD to 11 clean hydrogen projects through its Hydrogen Allocation Round 1 (HAR 1) process (ranging between 5-24.5 MW in size) with an average LCOH of around $10/kg. This was higher than much of the market expected. Three of the 11 projects signed 15-year low-carbon hydrogen agreements with the scheme administrative body, the Low-Carbon Contracts Company, in December 2024. The Hydrogen Allocation Round 2 formally opened for applications in December 2024.

In April 2024, for projects based in Spain, Portugal, Norway and Finland, the European Hydrogen Bank allocated its first production subsidies, ranging between €0.37-0.48/kg. The subsidies were allocated following a competitive auction and are intended to act as a bridge between the market price offtakers are willing to pay and the costs required to make projects viable. Compared with the UK HAR 1 projects, the outcome here was subsidies lower than most of the market expected to see. This result was most probably driven by a highly competitive first bidding round (as opposed to significantly lower costs of production), and subsequent rounds are expected to see higher subsidy levels before settling on a longer-term equilibrium.

At the end of 2024, the European Commission launched its second EHB auction. For both the HAR1 and EHB subsidised projects, the next gating item will be to see how many and how quickly these projects can start construction.

Case studies: Holland Hydrogen I and OranjeWind, Netherlands

Shell's Holland Hydrogen I 200 MW electrolyser project is one of the first large-scale green hydrogen projects to achieve FID in the world in 2022. Production of c. 22 kilotons per annum (**ktpa**) of green hydrogen using wind power from Hollandse Kust Noord wind farm (also partly owned by Shell) is expected to commence in 2025. The project was financed by Shell without external funding, and the entire offtake will be taken by Shell's nearby petrochemicals refinery, transported by a new hydrogen pipeline developed by the Port of Rotterdam and Gasunie.

TotalEnergies' 350 MW electrolyser project, also in the Netherlands, will reach FID in July 2025 and has a similar project structure, with power coming from its newly acquired 50% stake in the OranjeWind farm under development with RWE. The offtake will also be entirely by TotalEnergies' nearby petrochemicals refineries.

Shell and EWE are developing similar projects in Germany, both of which also reached FID in Q3 2024, and others are expected to follow a similar model across the region.

Ammonia Export / Import

Many of the most advanced clean hydrogen projects across the globe are focused on producing ammonia derived from hydrogen. This generally involves producing clean hydrogen in regions of the world with optimal cost conditions, conversion of that hydrogen into ammonia on-site using the Haber-Bosch process, and then shipping the ammonia (or an ammonia derivative, such as ammonium nitrate) as an export product.

Unlike hydrogen, ammonia can be readily transported by ship – some 10% of the world's ammonia is already transported by sea. This allows developers to select jurisdictions with optimal cost conditions and renewables availability for their production projects. Ammonia being a product used throughout the world, the ammonia can then be shipped wherever there is demand, allowing for a much more flexible offtake strategy.

These projects typically target demand centres and subsidy regimes in Europe, South Korea and Japan. Successfully obtaining import subsidies is an important feature of most clean ammonia export projects. A key issue to watch these projects is when and how they will implement financing solutions.

Another key issue for such projects includes structuring bankable offtake arrangements. These have similarities to LNG, but with additional issues such as risk allocation relating to compliance with clean ammonia specification standards in target markets and change in law, as well as risk allocation relating to intermittency of power sources derived from renewables (for green ammonia projects). Low carbon hydrogen is also very different to LNG in terms of pricing dynamics and scale and flexibility in terms of available destination markets and spot trading, and it will likely remain so until significantly beyond 2030.

Case study: NEOM, Saudi Arabia

NEOM Green Hydrogen is the largest clean hydrogen project under construction in the world, and the first large-scale project to achieve financial close (in May 2023) with a limited-recourse project financing, raising c. $6bn. The project will produce hydrogen using solar and wind power, which will then be converted into green ammonia, with production expected to start in 2026.

NEOM is a joint venture between Air Products, ACWA and Saudi Arabia's Public Investment Fund. Air Products signed a 30-year offtake agreement for the entire output of the project, acting as an aggregator and taking responsibility for selling the ammonia onwards. Such strong offtaker support from a cornerstone investor was the essential factor underpinning the project's bankability for project finance.

In respect to LNG, parties acting as aggregators, much like Air Products in this hydrogen project, have driven much of the LNG market and made large-scale liquefaction projects bankable. However, in the case of clean hydrogen, with uncertainties in the downstream green ammonia offtake market around price and volume risk, this model may not necessarily become the norm for the first wave of export projects.

In July 2024, Air Products reportedly signed a 15-year contract to supply 70 ktpa of clean hydrogen to TotalEnergies' European refineries, responding to a 500 ktpa tender offered by TotalEnergies. While such hydrogen is not expected to come from NEOM, this contract demonstrates continued appetite for signing large-volume offtake contracts for clean hydrogen.

In addition to Saudi Arabia, Oman has attracted great interest and granted development rights to at least eight such projects using this model (with several targeting first production by 2027). The UAE, Egypt, Morocco (see our latest briefing on Morocco's hydrogen framework), Namibia, India and Australia also have several well-advanced, large-scale projects in development, based on attractive combinations of wind conditions and solar radiation levels.

Case Study: H2 Global, European import tender for export projects

In the EU, the H2Global import subsidy scheme aims to provide circa 10-year offtake contracts for imports of clean ammonia, e-methanol and synthetic sustainable aviation fuel. The first tender ran in 2023, with results announced in July 2024. The second tender is now open, as of February 2025, with a budget of between EUR 2.5bn and EUR 3bn. For reasons associated with budget allocation, the term for the second round is provisionally set at 9 years (rather than 10) and is intended to cover a delivery period between 2028 and 2036. The second round has regional lots (reserved for production projects in Asia, Africa, North America, South America and Oceania) and a global lot (which is region agnostic). Depending on the rules for each lot, the end product to be supplied may be ammonia, methanol or hydrogen. The global lot, which has an allocated budget of EUR 567m, is reserved for hydrogen supply. For export projects, this will most likely involve the shipping of ammonia with a provision for cracking the ammonia back to hydrogen before the product is made available for injection into the hydrogen networks at proposed delivery points in Germany or Netherlands.

Fertiglobe, a JV between ADNOC and fertilizer group OCI, was the only winner of the first tender. This relates to volumes deriving from the Scatec and Fertiglobe green hydrogen project in Ain Sokhna, Egypt, with volumes to be shipped from Egypt and delivered into North-West Europe. Supply is intended to commence with c.19,500 tonnes per annum in 2027, rising to up to 397,000 tonnes per annum by 2033. The cost is said to be around about EUR 811 per tonne (on a production cost basis, discounting transport and back cracking costs). A SAF tender was also launched and failed in making an award, with H2 Global quoting that volumes bid were too small at this stage.

A key benefit of H2 Global is the fact that it will seek to link offtake to end users, through its "double stage" procurement model. Stage 1 is acquiring volumes on a long-term basis from production projects. Stage 2 is then on selling on shorter term trades to end users, including 1 year supply / purchase agreements. Shorter term trades can ease the burden on offtakers who may have concerns or find it challenging to enter into longer term trades typically needed to underpin a production project investment case. The first of the sell side auctions is due to launch in 2026.

Green steel

Steel can be shipped relatively easily and benefits from a large and liquid offtake market, thus providing a baseline level of comfort to equity and debt investors given the prospect of merchant revenues and the availability of replacement steel offtakers. Moreover, clean hydrogen-based steel can achieve as much as a 95% CO_2e emissions reduction compared with conventional steel, and offtakers are willing to pay a green premium as a result. Steel also represents a very small proportion of the cost of many offtakers' end products (such as cars), so the premium is absorbable and capable of being passed on to consumers.

Additionally, a shortage of low-carbon steel is expected in coming years as carbon taxes set in, which has, for example, helped the H2 Green Steel project (see box) to lock in relatively long-term offtake contracts with a wide portfolio of offtakers. Such long-term offtake is rare for steel and has helped to underpin the bankability of the project. Recent EU regulatory developments have also confirmed that clean hydrogen-based steel will be specifically eligible for EU emissions allowances, which can be sold for an additional source of revenue.

Case study: Stegra (formerly H2 Green Steel), Sweden

The H2 Green Steel project in Sweden includes the largest electrolysis facility (740 MW) under construction in Europe, and one of the largest in the world. The hydrogen production facility will be integrated with a direct reduced iron (**DRI**) plant and a sheet steel manufacturing plant. The project signed a c. €4bn project financing in December 2023, a world first for a clean hydrogen project with offtake (of green steel) on arm's-length commercial terms. Construction has made significant progress, and first production is expected in 2026.

H2 Green Steel benefits notably from being in a region of northern Sweden where, thanks to an abundance of hydroelectric power, nearly 100% renewable baseload electricity can be taken from the grid at low cost, without needing to build additional renewable energy capacity and without the intermittency issues of solar and wind.

The project exemplifies how geographic location will often be central to the business case of a clean hydrogen project. Indeed HYBRIT, a pilot green steel project developed by Vattenfall, LKAB and SSAB, which is already producing small volumes of steel and is gearing up for an industrial-scale expansion, is also located nearby in northern Sweden.

Various investors are looking at developing similar steel projects to the Stegra and HYBRIT projects in other regions of the world with plentiful hydroelectric power, but also in regions with optimal solar conditions such as Oman. Some projects plan to produce DRI pellets (rather than finished steel products) using hydrogen, which would then be shipped to steelmakers in countries with existing steel manufacturing facilities, reducing capex requirements.

Long-duration storage

The benefits of short-term storage of clean hydrogen have been questioned because of the energy inefficiency of producing hydrogen using electricity and then turning it back into electricity or heat. It seems clear that batteries are better suited to short-duration storage, but long-duration hydrogen storage has a viable case for storing excess renewable power (when the sun shines or the wind blows but demand is low) and dispatching it when needed to balance seasonal variations or unexpected power shortages.

Salt cavern storage for hydrogen is a mature technology and has been used in the UK (which has particularly strong storage potential) since the 1970s, but developers are also exploring other forms of geological storage in abandoned oil wells and saline aquifers (which are proven technologies in the oil and gas sectors).

Case study: Advanced Clean Energy Storage (ACES) Delta I, Utah

The ACES project is well into construction and expected to be operational in 2025. It will use curtailed solar power generated by the Los Angeles Department of Water and Power (**LADWP**) to produce clean hydrogen and store it in salt caverns capable of holding 300 GWh of energy (equivalent to 800,000 shipping containers of lithium batteries).

The hydrogen will initially be co-fired with natural gas in an 840 MW peaking turbine owned by LADWP, which is intended eventually to run on 100% hydrogen. The project operates on a tolling model where a fee is charged to LADWP for use of the electrolysis and storage facility, which was developed by Mitsubishi Power and Magnum Development with a $500m loan from the US Department of Energy.

ACES plans to roll out more projects across the US, and developers are looking at opportunities across the world where potential exists.

Shipping fuel

In January 2024, the EU ETS was expanded to cover emissions from all large ships entering EU ports. The first phase of FuelEU Maritime began in January 2025. It requires all ships entering the EU to gradually reduce emissions – modestly at first, but ramping up sharply: 2% by the beginning of 2025, 6% by the beginning of 2030, 14.5% by the beginning of 2035, 31% by the beginning of 2040, 62% by the beginning of 2045 and 80% by the beginning of 2050.

These regulatory developments are accelerating the shipping industry's interest in clean hydrogen-based e-fuels and ammonia. Data on shipyard orders over the past two years show that operators are ordering vessels capable of using e-methanol and green ammonia as fuels. Both have challenges and uncertainties in terms of being rolled out at scale, but the order data shows vessel operators are investing in the optionality to transition to clean fuels.

E-methanol is expected to be more expensive to produce than ammonia, as it requires synthesis of clean hydrogen with biogenic or captured anthropogenic CO_2. E-methanol projects, therefore, will need to be located where the cost of clean hydrogen production is sufficiently low and access to a reliable and cost-effective source of CO_2 is available.

Although ammonia is expected to be easier to produce, it is subject to safety challenges in that there is currently no safety standard enabling ammonia to be used as a maritime fuel. That said, work on designing safety cases is ongoing.

Aviation fuel

The EU is implementing policies for aviation fuel similar to those for shipping, with its ReFuelEU policy requiring that from January 2025 all fuel in EU airports contains a minimum 2% share of sustainable aviation fuel (**SAF**), which will rise over time. By 2030, a minimum share of synthetic fuels will be required, also rising over time. Synthetic fuels are those produced using clean hydrogen rather than derived from biomass, which is currently the main method of SAF production.

Clean hydrogen-based jet fuel is known as e-kerosene or e-SAF. Projects have been slower to take off than other e-fuels because of the cost of production, which is around 10 times that of fossil kerosene. That cost multiple has proven difficult to pass onto consumers, who are very sensitive to airline ticket pricing in the commercial aviation sector. However, ReFuelEU and similar policies are forcing demand to be created, and developers are responding to that demand.

The EU also decided in 2024 (after much debate) to permit the use of pink hydrogen (produced using nuclear power) to make SAF for the purposes of ReFuelEU. Although pink hydrogen projects are in very early stages of development, EDF has already announced plans to produce pink hydrogen at Hinkley Point C in the UK, which would be a world first.

For further detail on low-carbon maritime and aviation fuels, see our latest briefings on EU regulatory developments for low-carbon fuels in the transport sector and structuring and procurement issues for green fuels projects.

TECHNOLOGY, SUPPLY CHAIN AND CONSTRUCTION ISSUES

The procurement and construction side of clean hydrogen projects continues to face challenges.

Technology risk

Although there appears to be general underlying technical confidence in the ability of electrolysers to meet basic performance requirements at scale, the optimum configuration of renewable generation, storage and electrolysis assets remains a work in progress, and early mover projects are bearing the cost of 'learning by doing'. We will watch with interest to see whether, as anticipated by many, pressurised alkaline electrolysers will dominate market share on larger projects, whether polymer electrolyte membrane (**PEM**) electrolysis can achieve parity, or if a newer technology can drive in a wedge and dominate. Where there is increased intermittency in the renewable generation source, the ramp-up and ramp-down ability, and load-following capability, of these platforms is a critical consideration and a focus of required performance criteria in delivery contracts.

Supply chain bottlenecks

A key challenge for clean hydrogen projects is the lack of developed supply chains capable of meeting volume targets, not only for electrolysers but also rectifiers, inverters and other equipment needed by clean hydrogen producers.

Electrolyser OEMs are scaling up, but not at a pace which will satisfy anticipated demand levels by 2030. Understandably, until other perceived bottlenecks in relevant permitting and regulatory regimes are unlocked and, perhaps, something is done to deal with competition from foreign imports (see below), OEMs are not willing fully to commit the capex levels required to build out their production capability. They are also competing for various raw materials which are critical parts of other booming sectors, such as Battery Energy Storage Systems (**BESS**) and the EV battery sector.

China

European electrolyser OEMs are already concerned about losing business to their counterparts in China, with which they say they simply cannot compete because the playing field is not level. They have recently united to lobby the European Commission to do more to defend the European electrolyser industry from following in the footsteps of PV panels and BESS solutions in effectively ceding the dominant global market share to Chinese competition. Further, the European Hydrogen Bank's second round subsidy auction will require bidders to prove that no more than 25% of the electrolyser stacks, including surface treatment, cell unit production and assembly, are to be sourced from China.

To demonstrate the scale of the challenge they face, European electrolyser OEMs point to the fact that fewer than half of the projects which were successful in the recent EU hydrogen bank pilot auction plan to rely on European technology. They are consequently lobbying for more robust 'resilience criteria' to be included in the assessment factors for access to European support and subsidy schemes going forward. Similarly, US OEMs have complained to government and energy industry groups that an allegedly heavily subsidised price of electrolysers from Chinese OEMs makes their competitive position untenable.

To the extent that Chinese OEMs do take up market share, we anticipate seeing lenders and investors continuing to turn their ESG lens onto ensuring, to the extent possible, that Chinese suppliers are complying with relevant international standards in terms of raw materials sourcing and working conditions in their supply chains.

Contracting models and sole source

In light of these issues, it is not surprising that procurement structures are not settled in the clean hydrogen sector. We are seeing various options being deployed, from alliance-based and disaggregated EPCM-style models, through to traditional lump sum EPC structures. For projects seeking project finance, the variety of procurement structures has led to a similarly broad spectrum of contingency levels and sponsor support packages being required. The less risk that is passed to a creditworthy EPC contractor within its price, the more lenders will look to sponsors to plug the gaps.

As in other sectors, scheduling concerns are often paramount given developers' desire to benefit from first mover advantage. This has given rise to a number of fast-track procurement strategies being deployed. One such structure is two-stage or convertible EPC contracting. This envisages the appointment of a single contractor under a pre-construction services agreement (**PCSA**) to carry out the FEED and develop pricing for EPC delivery before conversion, at a pre-agreed point, into a fixed price EPC contract.

The advantage of this structure is that it allows the overall procurement time frame to be condensed by dispensing with the separate tender and evaluation phase for the EPC contract (which can last months). It is attractive to contractors as it allows them to secure the more lucrative EPC prize at an early stage, whilst de-risking the works via design development and site investigations as part of the FEED.

However, the reality is that a fully wrapped EPC can be difficult to achieve where the technology is novel, or untested at scale, as is the case for clean hydrogen projects. In a two-stage/convertible EPC process, contractors are able to use the increased bargaining power they enjoy from being in an effective sole source procurement (after they have been selected to carry out the FEED) to push for more favourable pricing and for more risk to sit with sponsors in relation to unforeseen circumstances. We are seeing this dynamic play out in a number of projects.

Sponsors will, therefore, want to structure the tender and evaluation process such that competitive tension is achieved and sustained throughout, thereby improving the chances of obtaining pricing and risk allocations which align with their financing aims. There is no single method that works for clean hydrogen projects in general. Rather, it is a question of applying one or a number of best practice techniques, which might include requiring bidders to tender a fixed EPC margin from the outset, withholding a portion of the PCSA fee until the EPC contract price and key terms are agreed, building in regular milestones during the PCSA services phase for the negotiation of the outstanding EPC terms, and ensuring the PCSA deliverables can be used if the EPC conversion is not with the original contractor.

It may also be possible to run parallel FEEDs (i.e., procure FEEDs from two (or more) potential EPC contractors, one of which would then be discarded on conversion into the EPC phase) in order to maintain competitive tension. However, few developers in the clean hydrogen sector have shown the appetite (or, more pertinently perhaps, had the early-stage budget) to incur these additional costs, despite this approach arguably representing the most effective way to maintain negotiation leverage and achieve the required risk allocation and pricing outcomes overall.

Electrolyser OEMs

The electrolyser market is still nascent for utility-scale clean hydrogen projects. As a result, OEMs come in all shapes and sizes (unlike, e.g., wind power where the turbine supply market is now dominated by a handful of major names). Some of these outfits are capable of delivering whole-plant EPC solutions as part of their offering, but some are too small to be viable EPC options. To compound matters, we are seeing some OEMs push to horizontally disaggregate their offerings, with engineering, supply, installation and performance guarantee elements split out between separate contracts and business lines within the same corporate group, with obvious potential consequences on 'wraps' and recourse levels for sponsors and lenders. Since the beginning of the current clean hydrogen cycle, we have seen a number of sponsors pushed into accepting these structures with a view to securing engineering and manufacturing availability in a "hot" market, often before legal and financial advisers are onboarded (although the current "cooling" market may now introduce more equilibrium in the discussions); once enshrined, these structures are often difficult to improve upon, and lenders will factor this into their contingency and equity support requirements.

THE PATH TO 2030

The past 12 to 18 months have clearly presented challenges for the rollout of clean hydrogen projects across the globe. However, we have seen significant progress in resolving pricing and risk allocation gaps between producers and end users. This has largely been driven by carbon tax regimes and regulatory interventions. Subsidy regimes have emerged across the globe, and, other than in the United States, we expect 2025 to be a hugely important year in the running of further subsidy allocation rounds. For those projects seeking to achieve COD before 2030, sequencing and timing challenges remain in terms of lining up all of the necessary pieces of the value chain. However, experience and data from the entrepreneurial endeavours in the sector over recent years have made it clear as to what works and what is sustainable. Although the "market" is still in its infancy and finding itself, it is nonetheless emerging as a diverse and dynamic market, potentially capable of delivering on the initial best use cases for clean hydrogen.

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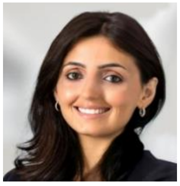

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