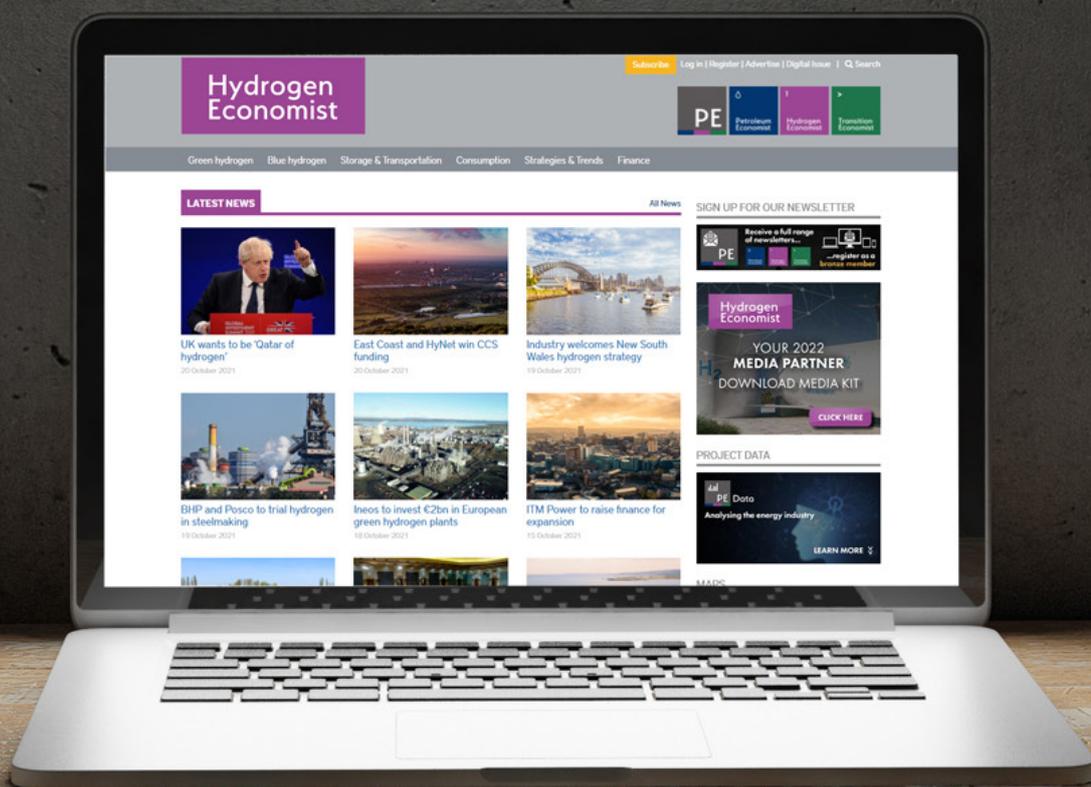


Hydrogen
Economist

Best of
Hydrogen Economist
2021



A collection of **Hydrogen Economist** articles published
between February 2021 and October 2021

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WELCOME

Informing the H₂ future

The rise in hydrogen's profile has been spectacular. Yet we are only at the start of the journey.

Hydrogen Economist

While we officially launched *Hydrogen Economist* in January 2021, we had been covering the sector for much of the previous year as a sub-brand of *Petroleum Economist*. Among those unversed in the previously relatively niche area of grey hydrogen for industrial use, we can genuinely claim to be right up there in the ranks of the first analysts of the blue and green hydrogen revolution.

But even we, 18 months ago, could not have predicted how exponentially interest in hydrogen as a key tool in the energy transition arsenal would have grown. The number of players, projects and partnerships in the sector has continued to expand and shows no signs of slowing.

It is clear, even to those most sceptical about hydrogen—and we not only acknowledge that they exist but actively seek to understand and learn from their reservations—that some colour of much lower carbon hydrogen will play a role in the future energy mix. Even if this replaces grey hydrogen in existing applications and provides an alternative heat fuel for a limited number of hard-to-decarbonise industries, this will still represent a shift in demand that will require billions of dollars of investment to meet.

But hydrogen champions see the fuel playing a far bigger role, with research and innovation targeting any number of wider applications. That a future hydrogen economy will exist is not in doubt, its scope is one of the most exciting and dynamic questions within an energy transition debate that is already lively.

Here at PE, we have assembled a uniquely talented team to investigate this question in the most intelligent way we can. Our staff in London

and our global contributor network can call upon decades of experience in relevant disciplines—in conventional and clean energy, in transport, in policy and in regulation to name but a few.

And our *Hydrogen Economist* brand stands alone as a service dedicated to providing the highest quality of analysis entirely focused on the sector. Our daily provision of value-add insight into the biggest developments in the fledgling industry—not just redistributed press releases or coverage of flimsy agreements to collaborate—is a unique proposition.

That has been reflected in the *Hydrogen Economist* service rapidly growing a subscriptions base within the largest operators that have ambitions in the sector and within services firms, both financial and technical, that are also growing their hydrogen competencies. And some of the biggest hitters in the industry have already agreed to talk exclusively to us, a number that is increasing by the week.

But do not just take our word for this. Read the pages that follow, where we showcase some of the best *Hydrogen Economist* writing so far, articles that we selected to appear in a dedicated section with the prestigious *Petroleum Economist* print magazine.

We are confident that you will find them illuminating. And we urge you to join the expanding *Hydrogen Economist* community, at the very least through becoming a bronze member of our network, giving you access to three of these types of articles each month and priority access to our hydrogen webcasts, seminars and events. At the same time, you should perhaps ask yourself if you can afford not to be a full subscriber to the best hydrogen intelligence service around.

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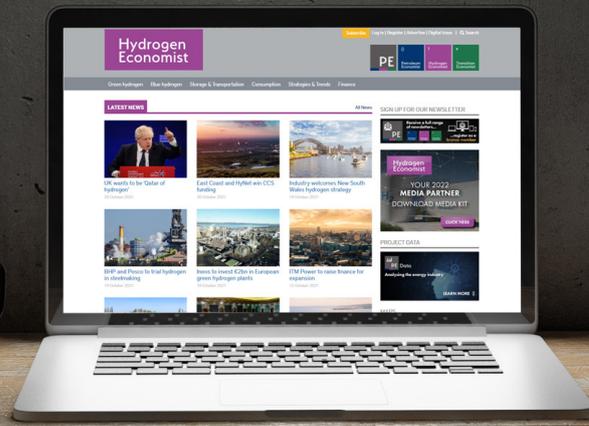
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Ballard Power is shifting gears

GREEN HYDROGEN / Fuel-cell company has made several recent agreements and is on the lookout for acquisitions and joint ventures / Vincent Lauerman, Calgary

Vancouver-based Ballard Power is forging new partnerships and collaboration agreements to help it commercialise and sell proton exchange membrane (PEM) fuel cells to manufacturers of buses, trucks, trains and ships.

The move comes despite the company shifting from being cash-starved to relatively cash-rich, with the stars finally aligning for ‘everything hydrogen’ over the past year or so.

Ballard has arrived at the point where it is filling sub-segments within its heavy-duty mobility business and working to provide more integrated PEM fuel-cell solutions to its customers by striking agreements with up-and-coming companies. This is rather than working with big-name companies as in the past.

In addition, Ballard is now on the prowl to acquire companies and invest in joint ventures that can support efforts to slash the cost of its offerings and enhance company revenue, Guy McAree, the company’s director of investor relations, tells *Hydrogen Economist*

Ballard signed two new non-binding memorandums of understanding (MoUs) in the first half of this month.

On 3 February, Ballard signed an MoU with Australia’s Global Energy Ventures (GEV), a relatively small company providing integrated compressed gas solutions for shipping. The pair are developing a new fuel-cell powered ship—called C-H2 Ship—designed to transport compressed green hydrogen. Ballard is to provide a PEM fuel-cell propulsion system up to 10MW for the prototype and an approximately 26MW system for the full-scale ship.

“GEV is a very competent company in



an up-and-coming industry, the transportation of hydrogen by ship, in which we had yet to become involved, having in the past collaborated with companies with smaller vessels such as ferries and river push boats,” says McAree.

A week later, Ballard signed an MoU with Atlanta-based Chart Industries, a manufacturer of equipment for the industrial gas and clean energy industries. This was for the joint development of integrated onboard liquid hydrogen storage and vaporisation systems for PEM fuel-cell powered vehicles.

“Chart Industries, a highly respected company, could help simplify the purchasing decision for [potential] customers of Ballard by providing a more integrated PEM fuel-cell solution, including onboard storage.”

Rags to relative riches

The financial fortunes of Ballard have changed dramatically recently, although it remains several years from profitability, providing the company a significant war chest to make investments and acquisitions.

Only back in July 2016, Chinese electric motor maker Zhongshan Broad-Ocean Motor Company finalised a \$28.3mn strategic investment for a 9.9pc stake in Ballard. Likewise, Weichai Power, a diesel en-

gine maker owned by the Chinese state, took a 19.9pc interest in the company for \$163.6mn in November 2018.

By contrast, in the past six months Ballard has raised almost \$1bn through three new share offerings, diluting ownership by a relatively small 17pc. “We have a \$700mn cash reserve, and we are actively looking for potential acquisitions and joint ventures,” says McAree.

One potential joint venture partner is German auto parts maker Mahle, he says, with which Ballard announced a strategic partnership last September. Ballard does not have PEM fuel-cell manufacturing capacity in Europe, but it does in China through a joint venture with its other strategic partner, Weichai Power.

On the acquisitions front, McAree says Ballard is planning to stick to its heavy-duty mobility focus, but there is one possible exception—electrolyser technology to produce green hydrogen.

“Broadening or deepening our stationary capabilities through M&A is not a high priority at this time,” says McAree, referring to Ballard’s relatively minor position in stationary backup power applications. “On the other hand, we are looking at companies that make electrolyser technology.”

Ballard could benefit from the sale of PEM electrolysers in three ways: by leveraging electrolyser sales to fund investment in fuel-cell technology; through technological synergies between PEM electrolysers and fuel cells since they simply perform the reverse function (water to hydrogen and vice versa); and to build additional scale across its supply chain. **PE**

“We are looking at companies that make electrolyser technology”

McAree, Ballard Power Systems

FIRST PUBLISHED 15 FEBRUARY 2021

Australia bolsters green hydrogen push

GREEN HYDROGEN / The fuel has received a surge of support from government and industry, and is set to benefit from the country's renewables boom / **Andrew Kemp, Melbourne**

Australia's federal and state authorities have thrown their weight behind clean hydrogen policies and associated pilot projects, with the goal of driving down green and blue hydrogen production costs over the next decade, and industry has responded positively.

The latest company to join the fray is Australian junior Strike Energy, which recently announced plans for a \$1.8bn ammonia and urea manufacturing facility in Western Australia that will include both blue and green hydrogen supply streams.

Canberra adopted its National Hydrogen Strategy in August 2019, noting that it wanted to "position the [hydrogen] industry as a major player by 2030". A key element of this strategy has been to encourage the development of hydrogen hubs that will drive large-scale industrial demand.

The vast majority of global hydrogen production is of the grey and brown varieties and, among low-carbon varieties, the commercial viability of green production lags that of blue. But Australia's ongoing renewable energy boom is set to help to bridge some of that divide.

The IEA has calculated that the cost of blue hydrogen production in the most promising regions is around \$1.4-1.5/kg, while the cost of hydrogen generated from renewable electricity is around \$2.5-6/kg.

The Australian government, however, wants to slash clean hydrogen's production costs to less than A\$2/kg (\$1.55/kg). In its first Technology Investment Roadmap, released last year, the government described the fuel as "transformative" with both industrial, power generation and transport applications.

The Australian National University (ANU) has found that Australia could lower green hydrogen production costs to below A\$3/kg within the next few years, with sub-A\$2/kg an increasingly viable prospect over the next decade.

Thomas Longden, a Fellow at the ANU's Crawford School of Public Policy and member of Zero-Carbon Energy for the Asia-Pacific Grand Challenge, tells *Hydrogen Economist* that not only could green hydrogen production costs ap-



Parliament House
Canberra

proach A\$2/kg but government scientific agency CSIRO's own power generation cost projections also suggest that lower prices might be feasible.

"Combining the CSIRO GenCost electricity cost projections for 2030 with electrolyser estimates from the IEA results in hydrogen production cost estimates of between A\$1.89/kg [for solar] and A\$3.71/kg [for wind]," he says.

Australia is in the middle of a green energy boom, with the Clean Energy Regulator reporting that renewables' share of the National Electricity Market topped 30pc in 2020, the first time it has done so. As renewable capacity expands, the commercial case for green hydrogen inevitably grows stronger.

The country has seen a string of projects green lit in recent years: from Western Australia's A\$51bn Asian Renewable Energy Hub—which will use 23,000MW of solar and wind power to produce green hydrogen and ammonia—to a A\$240mn, 40,000t/yr green ammonia plant backed by the South Australian state government.

While the iron's hot

The possibilities of green hydrogen have not been lost on the country's oil and gas sector either. Developers Woodside and Santos have grabbed headlines in recent months for their growing interest in green hydrogen. And the fuel has also caught the eye of the industry's smaller players.

The Strike Energy ammonia and urea manufacturing facility will include both

blue and green hydrogen supply streams, the company announced in January.

It has said that while its Greater Erregulla onshore gas development will provide the bulk of feedstock to the 1.4mn t/yr urea plant—dubbed Project Haber—the Western Australia facility will also include a 10MW hydrogen electrolyser.

Strike CEO Stuart Nicholls tells *Hydrogen Economist* that the company's decision to include green hydrogen capacity was a "bet both ways" on the future of hydrogen.

"Green hydrogen production and use at scale in an industrial setting is yet to be proved. While blue hydrogen is currently the only way to economically produce clean ammonia at scale, we want to be ready for any shift in project economics."

Strike wants to build the plant in an industrial area of the city of Geraldton, which has access to an abundance of wind power that exceeds local demand. "With wind prices falling close to zero in the evening, as a result of industrial demand in the area falling off, it creates arbitrage opportunities for the development," adds Nicholls.

While Strike is eager to demonstrate the viability of green hydrogen in ammonia production for environmental reasons, the company remains focused first and foremost on project economics. Moreover, if Strike is able to displace gas with green hydrogen it frees up new marketing opportunities for gas from Greater Erregulla. **PE**

FIRST PUBLISHED 11 FEBRUARY 2021

Sinopec aims for Chinese hydrogen leadership

GREEN HYDROGEN / Beijing-based company is seeking to collaborate in developing a supply chain / **Shi Weijun, Beijing**

China's Sinopec has provided a glimpse of its future in hydrogen following a meeting with four of the country's biggest solar energy players. The diversified oil and gas conglomerate is to prioritise hydrogen with the aim of becoming the leading domestic player.

Sinopec recently made public a video conference held last month with Golden Concord Holdings, Trina Solar, LONGi Solar and Tianjin Zhonghuan Semiconductor to discuss potential cooperation on renewable energy projects. Trina is one of the world's largest solar panels producers, while the other three private enterprises are leaders in different segments of the supply chain of materials used to make solar panels.

Sinopec produced more than 3mn t of hydrogen from its refineries in 2019, giving it a 14pc share of the domestic market that was second only to China Energy Investment Corp, the country's biggest coal producer. Much of this hydrogen was consumed within the company, however.

Sinopec is aiming to build up scalable high-purity hydrogen capacity during the 14th Five-Year Plan period, which

runs from 2021-25, which would make it the leading high-quality hydrogen vendor in China.

Sinopec discussed in the meeting its aim to capture opportunities to collaborate with the companies in developing a green hydrogen supply chain and to use its petrol station chain to distribute green hydrogen. The potential team-up indicates that Sinopec is moving towards green hydrogen, away from its brown hydrogen setup. And that it is looking to commercialise its hydrogen production by expanding further down the value chain into the transportation end-use market.

The partnerships make sense for Sinopec, which as Asia's largest refiner has built up considerable research and development expertise in chemical materials and operates the world's second-largest network of petrol stations—more than 30,000 at the end of last year.

Hydrogen will be the core focus of Sinopec's

new energy business, which also includes geothermal, company chairman Zhang Yuzhuo said during the meeting. "The room for multiparty cooperation in the new energy supply chain is vast," said Zhang.

14pc

Sinopec share of domestic H₂ production

Sinopec has expedited strategic moves in hydrogen in recent years. In July 2019 it built China's first integrated service station for petrol, diesel and hydrogen in the southern city of Foshan in Guangdong province. The company's second station opened in the city of Jiaying close to Shanghai in October 2019. The following month saw two stations in Shanghai built with technology from French industrial gas giant Air Liquide open for business.

Three more stations in Guangdong entered operation in December 2020, bringing the national total to seven at the end of last year. Another eight are anticipated to be completed in the first few months of this year, while Sinopec has previously stated an aim to build 20 integrated stations in Guangdong.

While Sinopec's early foray into hydrogen is unlikely to be profit-making at this stage, the move will help the NOC align with China's carbon neutrality goals and weather the eroding competitiveness of fossil fuels as global policy shifts towards tackling climate change.

Chinese President Xi Jinping pledged last year to make China carbon neutral by 2060 and said in December that the world's biggest consumer of fossil fuels would boost the share of non-fossil fuels

in its primary energy consumption to c.25pc by 2030 from a previous commitment of 20pc.

Other Chinese players that have advanced their hydrogen plans recently include CIMC Enric, which won a tender to supply mobile hydrogen refuelling equipment for a green hydrogen project by China Energy Investment, and Huadian Power International, which finished building China's first commercial-scale wind power-driven hydrogen plant in December. **PE**



FIRST PUBLISHED 16 FEBRUARY 2021



Hinkley Point
nuclear
power station
Somerset, UK

Nuclear should be 'at the heart' of hydrogen production

NUCLEAR / New reactor technology could provide one-third of zero-carbon hydrogen by 2050 / **Che Golden**

Nuclear power could produce one-third of the UK's clean hydrogen needs by 2050, according to the Hydrogen Roadmap agreed by the Nuclear Industry Council (NIC), a joint forum between the nuclear industry and government.

But the industry's ability to make itself central to green hydrogen could be either helped or hindered by the outcome of a joint research report, due to be published imminently.

The NIC produced a roadmap that claims Advanced Modular Reactors (AMRs), currently under development, offer one of the most promising innovations for green hydrogen production, since they will create temperatures high enough to split water without diverting electricity.

The roadmap estimates that 12-13GW of nuclear reactors of all types could use steam electrolysis using waste heat and thermochemical water-splitting to produce 75TWh of green hydrogen by 2050. The UK government has set a target for an AMR demonstrator by the early 2030s.

In the meantime, existing large-scale reactors could produce green hydrogen today at scale through electrolysis, as could the next generation of gigawatt-scale reactors. Small module reac-

tors, the first unit of which could be deployed within the next ten years, would offer possibilities for green hydrogen production near industrial clusters.

"Nuclear power should be right at the heart of green hydrogen production, alongside renewable technology," says Tom Greatrex, chief executive of trade body the Nuclear Industry Association and a former UK shadow energy minister. "Nuclear reactors offer the solutions we need to decarbonise sectors beyond electricity."

International outlook

However, there are concerns within the nuclear industry about European Commission plans to evaluate the safety of radioactive waste handling. The European Commission's in-house research body, the Joint Research Centre, is expected to publish a report soon that could either rec-

ognise nuclear power as a transition fuel under the EU's green finance rulebook or brand it as a polluting form of energy.

The classification of nuclear under the EU's green finance taxonomy will have an impact on the amount of financial support that governments will be allowed to give new projects under the EU's state aid rules. Private banks are reluctant to provide loans for new nuclear projects unless governments back them with financial guarantees and state aid.

Nuclear power, and its ability to compete head-to-head with renewables, has not gained the approval of S&P Global Ratings. According to the ratings agency, growing competition from cheap renewable electricity, safety concerns and rising costs of new plants are driving nuclear power towards obsolescence, except in Russia and China where it has extensive state support. **PE**

"Nuclear power should be right at the heart of green hydrogen production, alongside renewable technology"

Greatrex, Nuclear Industry Association

FIRST PUBLISHED 18 FEBRUARY 2021

Nel's alkaline production line set for test run

GREEN HYDROGEN / Norwegian manufacturer's CEO says it is too early to predict whether alkaline or PEM electrolyzers will ultimately prevail / **Matt Smith**

Alkaline electrolyzers will drive Nel Hydrogen's revenue growth over the next few years, the company's CEO Jon Andre Lokke tells *Hydrogen Economist*. These devices will eclipse Nel's two other main business lines—polymer electrolyte membrane (PEM) electrolyzers and hydrogen refuelling stations.

Nel is in the process of finalising its new, fully automated production line for alkaline electrolyzers, which will be the first of its kind globally. It took three years to perfect the automation of the previously manual production process. The production line will start a test run in mid-2021 before ramping up commercial production in the third quarter.

"The beauty of this production line is that we can replicate it anywhere. It is a standardised design," says Lokke, who estimates it will cut costs approximately in half initially. "The industry does not yet understand the implications of this breakthrough. There is the potential to cut the costs in half again by optimising and increasing production capacity further. Production will be faster and cheaper and use less energy, materials and labour."

Nel will steadily enhance its alkaline stack, increasing capacity from 2.2MW to around 10MW while slightly reducing the stack size so that it still fits into a 40ft shipping container.

PEM developments

The company recently also launched a 1.25MW PEM electrolyser stack, which is five times the size of its 250kW predecessor. The output of each new stack will be about 500kg/d.

"This larger size makes it feasible for us to deliver a 20MW PEM electrolyser plant to customers such as [Spain's] Iberdrola. If we were to attempt that with the previous generation, it would require



"The industry does not yet understand the implications of this breakthrough"

Lokke, Nel

some 80 stacks—that obviously would not work due to all the connecting parts required and would be extremely expensive," says Lokke. "Now we can do the same with 16 stacks—you get a manageable level of complexity."

Doubling the capacity to a 2.5MW stack should be easier, because Nel could simply add more cells and increase the stack height. It will start looking at automating PEM electrolyser production too, says Lokke.

Nel's PEM electrolyser plant is in Wallingford, Connecticut. "The US is an important market for PEM, but orders are quite small—you typically do not see as large projects on PEM as on alkaline because the cost is still higher

and the efficiency a bit lower in comparison," says Lokke.

As the two electrolyser technologies vie for supremacy, he believes alkaline is ahead, but PEM may possess greater potential. "This is a long-term technology hedge for us," he says. "After 2030, we could potentially see more focus on one versus the other."

Business pipeline

Lokke says his firm remains open to investing in other companies and could also make further acquisitions. "We want to have the flexibility if an opportunity arises—an investment would have to support the development of a new market or product, or ideally both," says Lokke.

Nel's fourth-quarter revenue rose by 30pc year-on-year, to NOK229.1mn (\$26.73mn), as its order backlog nearly doubled to NOK981.1mn. Its notable orders last year included a \$30mn deal with hydrogen fuel truck manufacturer Nikola for 40 electrolyzers, amounting to around 85MW, in what was the world's largest sale of its kind.

Meanwhile, Japan's Iwatani Corporation ordered 14 Nel hydrogen refuelling stations (HRS) for installation in California. Nel has delivered around 110 of these stations to 13 countries. They cater primarily for light vehicles such as passenger cars, but the company will switch its focus to building facilities to serve buses and heavy-duty trucks. "The key is to develop fast refuelling for these big vehicles," says Lokke.

This would entail delivering 50-100kg of hydrogen in ten minutes, which would give the same range and speed as diesel refuelling. "We do fuel heavy-duty vehicles already, but this is a slow fill and uses a tweaked light-duty vehicle station—this new product will be developed specifically for buses and trucks," says Lokke.

Nel believes it can lower green hydrogen costs to \$1.5/kg by 2025. Prices are around 3-5 times that currently, but the company expects the costs of both renewable power and electrolyzers to continue to fall, enabling green hydrogen costs to drop drastically. **PE**

90pc

Annual increase in Nel's Q4 2020 order book

FIRST PUBLISHED 19 MARCH 2021

North African nations vie for green opportunity

GREEN HYDROGEN / The renewables potential of Morocco and Egypt means they stand to gain from soaring European interest and the nascent international market / **Clare Dunkley**

North African nations—with huge capacity for renewable power generation and located a relatively short distance from potential key EU hydrogen markets—are in a prime position to capitalise on the international trade in green hydrogen that is expected to emerge over the coming decades.

Rabat created a National Hydrogen Commission 18 months ago and has recently been rewarded with a flurry of activity. In early March, an Italian corporate team agreed to consider jointly developing a plant. And just a month earlier Rabat and Lisbon pledged cooperation, echoing a more-detailed pact inked with Berlin in June last year.

The EU Hydrogen Strategy unveiled last July underpins a burgeoning interest in nurturing—and potentially financing—an export industry on the other side of the Mediterranean.

Lacking fossil fuels but gifted with plentiful sun and wind, the kingdom has leapt at the tumbling costs of renewable power generation, installing 3.69GW by end-2020. It has plans to increase this to 11GW by 2030, equivalent to 52pc of its expected electricity needs.

Utilising some of this to produce green H₂ presents obvious attractions, from stabilising the power grid, as the proportion of renewables increases, to reducing the need for costly gasoline and diesel imports. In addition, one of its export earners, phosphate-based fertilisers, sucks in 2mn t/yr of imported grey ammonia that could potentially be replaced by locally produced green hydrogen.

The prospect held out by the EU's Green New Deal, which promises access to finance for the lucrative new export industry, is undoubtedly accelerating cash-strapped Rabat's own plans.

Aligned with its national hydrogen strategy last June, Berlin committed to directing €2bn of the envisaged €9bn investment towards international partnerships. The agreement between the two countries later that month remains the kingdom's most-concrete to date, calling for construction of a 1MW pilot electrolysis facility that is scaleable up to 100MW.



Ouarzazate solar power station, Morocco

Morocco's declaration of cooperation with Portugal was more nebulous, calling for "aligning the green hydrogen priorities" of the two countries and collaborating to encourage commercial demand. Meanwhile, the Italian companies—Saipem and Alboran Hydrogen—announced they would consider establishing a green hydrogen production plant, without providing details.

Egyptian emergence

Egypt has been on an energy rollercoaster over the past decade, matched only by its political journey since the 2011 revolution. It is once again becoming a gas export hub while, like Morocco, rapidly becoming a regional clean energy leader. With installed solar and wind capacity having ballooned more than fivefold in five years, Cairo is similarly eyeing green hydrogen sector.

Egypt's wind and sunshine resources are abundant enough to maintain the pace of its renewables buildout. Capacity reached just over 3GW by end-2019, according to Irena. From generating just over 10pc of electricity from renewables, the government is chasing a self-set goal of 20pc by 2022 and 42pc by 2035.

Using a portion of the surplus renewable energy arising during periods of low demand to produce green hydrogen is now under serious consideration. This could either be used domestically in

power stations and for transport—freeing up gas for export and reducing the country's refined products deficit—or sold internationally as ammonia.

In January, German electricity titan Siemens inked an agreement with the Ministry of Electricity and Renewable Energy (MERE) to carry out a pilot project.

The following month, President Abdel Fattah el-Sisi hosted a Belgian business delegation to discuss renewables investments; an accord was struck in early March between Belgian marine engineering conglomerate Deme, MERE, the Ministry and the Egyptian Navy to trial green hydrogen production.

Deme, which has been diversifying into offshore renewables, is working locally on the expansion of Abu Qir port near Alexandria. It took its first step onto the nascent regional green hydrogen scene in December, when it agreed to develop a production plant at Oman's Duqm port.

Egypt has so far has been focused on green rather than blue hydrogen, despite the latter's potential as an alternative outlet for rapidly rising gas production. It is also focused on domestic use, although its fertiliser export infrastructure could be deployed for blue ammonia sales should the still-fledgling international green hydrogen market take off. In the meantime, with global gas demand still climbing, the green option is set to be the priority. **PE**

FIRST PUBLISHED 24 MARCH 2021

Wind could power Scottish green H₂ revolution

GREEN HYDROGEN / Floating offshore windfarms could utilise huge untapped resource and make Scotland a major player in the EU hydrogen economy / **Alastair O'Dell, Senior editor**

Scotland's territorial waters have the capacity to generate a colossal 170GW of power and, if even a fraction of this is used to produce green hydrogen, it would establish the country as a major supplier to key Northern European markets.

But while the UK is a leader in offshore wind, floating wind remains in its infancy and no hydrogen has been produced offshore at scale. *Hydrogen Economist* spoke to two of the experts behind a Xodus Group report on the topic: Graham Barton, senior field development study manager, and Jakub Vrba, renewable energy consultant.

Why are Scottish waters so promising for green hydrogen production?

Vrba: Scotland has huge potential for floating wind, but the grid is already constrained. There would be a lot of untapped potential if we do not produce hydrogen. We see green hydrogen really taking off in the coming years.

Barton: Realistically, there is going to be a floor on the cost of power from wind turbines 150km offshore—it is never going to be the cheapest form of renewable energy. But things change when you add in the cost of transportation to the big German and Dutch markets. We believe 100TWh/yr is credible, and we estimate this could satisfy about 10pc of the long-term EU market. The volumes we will need by 2050 mean there will not be one dominant source—it will require 'all hands on deck'.

Will supply constrain consumption for the foreseeable future?

Vrba: Until 2030, the export market will be regional. From 2030, we will see a more integrated market and longer distance shipping—that is when North Africa will start competing.

Barton: The first EU market for green hydrogen will be displacing the 400TWh/yr of industrial grade grey H₂ used principally for petrochemicals, ammonia and



"We believe 100TWh/yr is credible, and we estimate this could satisfy about 10pc of the long-term EU market"

Barton, Xodus

high-temperature applications. Where demand sits near a cluster it may go to blue H₂—but demand is very dispersed and in many instances it will prove easier to switch to imported green H₂.

Long term, what level of carbon tax would be necessary?

Vrba: Green and blue hydrogen will not be able to compete unless there is an incentive—whether a carbon price or government-led initiative such as contracts for difference. Definitely for the next decade, probably beyond. It depends on the sector, but a ballpark \$100/t of CO₂ would help hydrogen penetrate most markets.

The UK seems to favour blue hydrogen—is it interested in green?

Barton: I am not decrying the UK fund-

ing blue hydrogen and CCS clusters to keep Feed studies and pilot projects going. But CCS captures about 90pc of CO₂ and there are concerns about fugitive methane emissions—so blue hydrogen is not 'zero' carbon. And as we have plenty of existing CO₂ to capture already—why would you fill up valuable storage sites with CO₂ that you can avoid? That may be too simplistic, but the long-term direction has to be green.

The EU has a world-leading hydrogen strategy. Might EU producers get preferential treatment? Does Brexit matter?

Vrba: As long as Scotland can prove its hydrogen has come from renewables and can compete on price, I see no reason why EU countries would not import it. But Brexit will play a key role in funding for R&D and pilot projects. Scotland will find it difficult to tap these large funds whereas it will be easy for Ireland. That is where I see the danger.

What are the next steps?

Vrba: The Dolphyn project will be the first floating wind turbine with hydrogen production offshore anywhere. Once proven, the next step would be a proper pilot. Then, when we look at 1GW+ windfarms 100km out, hydrogen production offshore would start to make sense—but this is definitely not something we will see even in the next ten years.

Barton: If we did it at scale today, green hydrogen would be something like \$7/kg and no one would buy it. The technology will happen. What is most needed is the commercial environment—the pricing, the economics—and that must be market-led. We will only get beyond subsidised demonstrator projects once the commercial environment allows companies to undertake multiyear, billion-dollar projects. **PE**

The full interview is on the Hydrogen Economist website

FIRST PUBLISHED 26 MARCH 2021



The Vopak terminal at the Port of Amsterdam

Vopak targets leading role in hydrogen trade

STORAGE / Commodity storage company has up to €350mn available to invest in hydrogen projects this year as it pursues a strategy built on global port presence / **Alastair O'Dell, Senior editor**

Dutch commodity storage company Vopak is setting itself up to play a crucial role in the growing worldwide trade in hydrogen, which it sees as one of the vital energy products of the future, its recently appointed global director of new energies tells *Hydrogen Economist*.

The Rotterdam-based firm, which has traditionally focused on storing oil and chemicals, is placing bets for future business growth on storing new types of energy carriers, including hydrogen.

“We believe that hydrogen will ultimately develop into a globally traded energy commodity in which Vopak’s infrastructure can play a crucial role to facilitate and balance global supply and demand,” says Marcel van de Kar, who started at Vopak more than 25 years ago and was appointed into the newly created role of global director of new energies last month.

“It is exciting to be leading Vopak’s efforts to enable new supply chains and facilitate the vital products of the future,” van de Kar says. “It is an area in which co-operation between very different parties around the world is the key to success.”

Vopak’s strategy is to build on its presence in the world’s major ports in order to eventually offer hydrogen-linked storage options to customers across the globe. The company is already active in storing ammonia at five terminals in Asia, the Middle East and North America.



“We believe that hydrogen will ultimately develop into a globally traded energy commodity”
van de Kar, Vopak

“Location presence is always crucial,” according to van de Kar. “An independent operator such as Vopak supports investments in open-access infrastructure for multiple users, which makes it more cost efficient for the industry.”

Target projects

Vopak plans to invest in hydrogen and ammonia infrastructure to import and distribute the commodities at large scale in the world’s main energy and industrial demand centres. To start, Europe presents the most promising area. “Given Europe’s ambitious climate goals, we focus specifically on how to facilitate imports of hydrogen into the Netherlands, Belgium and Germany, with potential supply chains originating in southern Europe, Morocco, the Middle East and South America,” van de Kar says.

Vopak has set aside €300-350mn (\$352-411mn) to invest in growth projects this year, and most of it has been earmarked for spending in the new en-

ergies division. The company is involved in more than ten different projects in this space, including one investigating—jointly with partner Hydrogenious—the possibility of bringing hydrogen stored in liquid organic hydrogen carriers (LOHC) from a plant under construction in Germany to Rotterdam.

Storing and transporting hydrogen will be key to its devel-

opment into a global traded commodity. Next to LOHC technology, Vopak also sees liquefaction and transforming hydrogen into green ammonia as important ways to enable transportation and storage of the fuel. “Each technology has its own advantages and disadvantages, but the various technologies are key to developing global hydrogen supply chains,” says van de Kar.

Vopak’s involvement in LOHC is the direct result of its €17mn investment in Hydrogenious in 2019, through Vopak Ventures. Two funds, one dedicated to sustainability investments and the other to digitalisation, allow the 400-year-old company to get involved in new technologies at startup level. So far, the funds have invested in nine companies and Vopak’s typical investments vary between €0.5-10mn.

Other investments include HyET Hydrogen, a manufacturer of commercially viable Electrochemical Hydrogen Compressors, and HyEt Solar, which produces extreme lightweight solar modules. **PE**

FIRST PUBLISHED 10 MARCH 2021

FiveT bullish on hydrogen fund prospects

FINANCE / The industry-backed hydrogen fund says it ticks all the boxes for clean investment / **Tom Young**

The FiveT investment fund launched in April, aimed at raising €1bn (\$1.2bn) from financial and industrial investors to finance projects in the production, storage and distribution of clean hydrogen. The fund will receive investment from fuel cell firm Plug Power, engineering firm Chart Industries and energy technology company Baker Hughes.

The fund will be led by Pierre-Etienne Franc, who was the vice president of hydrogen energy for industrial gases company Air Liquide and co-secretary of the Hydrogen Council until becoming FiveT CEO. *Hydrogen Economist* spoke to Franc to find out more.

What will you invest in and where?

Franc: We will look to fund scale projects in the hydrogen value chain. It is not time anymore for demonstration projects upstream or downstream, we need to see projects at size for which our typical investment would start at €20-30mn.

We would be seeking projects where there are support policies in place that enable sustainable economics.

The projects need to have a potential for delivering a double-digit return through the combination of revenues economics and the asset value. Really, it is an asset play, which is why it is an infrastructure fund.

We are not going to invest into carbon capture and storage. Oil and gas players are better equipped to do so. But if some hydrogen is coming from a blue hydrogen scheme into infrastructure we have funded, of course that is not an issue.

Initially, investments are likely to be

€20-30mn

Size of investments targeted

in Europe because that is where we see the most support in terms of contract for difference (CfD) schemes and so on, although we will probably see the same kind of schemes in the US eventually and some US projects could have solid economics as well on their own.

On Asia the jury is out. Asia is supportive of the technology, but it is mostly downstream so far. There are scheme that could be well suited for investments, so we will keep an eye on it.

Are there other funds?

Franc: There are some funds that exist in the hydrogen space, but we are the first to focus purely on infrastructure.

How is awareness?

Franc: There is not one single week without a report coming out on hydrogen. Hydrogen is there to play a systemic role in the energy play of the future, and everybody is waiting for the right business model to get out there and invest heavily.

They have invested in the stocks of companies in the hydrogen space already, and now hopefully they will invest in projects. These are the ones our fund want to foster.

The fund is ticking a couple of the key boxes if you want to be a green investor, and we are aligned with the goals of the Taskforce on Climate Related Disclosures and the European taxonomy on green investments.

We will have to develop the proper ESG key performance indicators in the way we manage the projects.

The flow of money into the sector is still nascent. This is where hopefully initiatives like this fund will trigger further investment. You have to get infrastructure in place, and everything will cascade from there—scale is an important element to make costs go down. That dynamic should, in turn, help deepen access to financial markets and release further investments.

If we demonstrate that the fund is the right one then there will be massive inflow of new players waiting to join the game.

Will you be technology-agnostic?

Franc: We are going to be technology-agnostic. We are not going to choose one versus another. We are going to have in the fund some expertise to make sure we can evaluate what our partners are saying—but we just want the technology that works best at scale.

What are the best policy mechanisms to support investment?

Franc: On funding, CfDs are fundamental. They help customers shift to green hydrogen without having to support the financial burden initially. It could be linked to a carbon price, but the main thing is it needs to be secured for a certain period of time.

We need mechanisms that enable multi-annual support to cover the cost of producing green molecules rather than grey ones. We will need same other mechanism downstream to pay for distribution assets—potentially public-private partnership schemes are best for that sector.

On capex there is a relatively solid support system in many countries. In the US, we hope there should be some more space for hydrogen support. **PE**



FIRST PUBLISHED 20 APRIL 2021

Fortescue bets big on green hydrogen

GREEN HYDROGEN / Iron ore miner eyes massive push into renewables and clean gas production / Vincent Lauerman

Fortescue Metals Group may be only a second-tier global mining company based on revenue, but the Australia-based iron ore producer, founded in 2003 by multi-billionaire Andrew Forrest, appears to have the grandest green hydrogen ambitions of them all.

The company is aiming to make its mining-related operations carbon neutral by 2030, with Fortescue Future Industries (FFI), its wholly owned renewable energy business, providing the green hydrogen, ammonia and electricity needed to do so. FFI hopes to be producing green hydrogen at commercial scale as early as 2023.

“Green hydrogen is the cleanest source of energy in the world, and optimising the technology to produce green hydrogen at scale and at a competitive price to fossil fuels is the key to meaningfully reducing global greenhouse gas emissions,” FFI chief executive Julie Shuttleworth tells *Hydrogen Economist*.

“Climate change is one of the most pressing issues facing the planet today, and to achieve the target established by the Paris Agreement, the broader energy transition will need to happen far more rapidly than 2050. We want to lead by example at Fortescue, which is why we have announced an ambitious, revised target to achieve carbon neutrality by 2030,” Shuttleworth says.

Fortescue’s ambitions for FFI include exporting green hydrogen to steelmakers and other heavy industries to support their decarbonisation efforts, and to possibly even become a vertically integrated green steelmaker itself, according to Forrest.

“Fortescue is currently conducting trials in preparation for a green steel pilot



“Optimising the technology to produce green hydrogen at scale and at a competitive price to fossil fuels is the key to meaningfully reducing global greenhouse gas emissions”
Shuttleworth, FFI

plant, and it is too early to comment further on any other details of the project,” Shuttleworth says. The company is understood to be planning a green steel pilot project in the Pilbara region.

Grand ambitions

FFI says it has identified a massive pipeline of 300GW of potential renewable power projects around the world—including 40GW in the Pilbara region of Western Australia—with the hope of building as much as 1,000GW of capacity in the longer term, much of it for the production of green hydrogen. To put the scale of these ambitions into context, global additions of renewable capacity in 2020 came to 260GW, according to the International Renewable Energy Agency.

“We aim to provide the two missing links in the climate-change battle—creating both the demand for and supply of green hydrogen and green ammonia,” says Forrest.

To support FFI’s efforts, Forrest and members of Fortescue’s management

team spent four months travelling the globe in the latter part of last year in search of potential renewable energy projects and related mineral resources.

The company has remained relatively tight-lipped about the trip overall, but during its annual

general meeting in November it was revealed the group planned to visit up to 47 countries. In addition, on 14 December Fortescue announced the signing of a memorandum of understanding with Japan’s Kawasaki Heavy Industries and Iwatani Corporation to form the Global LH2 Consortium to create a business model to export liquid hydrogen from Australia to Japan.

“We know there will be many key markets for green hydrogen in the coming decade and, by building on our existing supply chain capabilities and market access, we see an opportunity for Fortescue to participate in, and be at the forefront, of developing an export market for hydrogen,” Shuttleworth says.

Fortescue has also set a deadline of 30 June for a number of key FFI initiatives. These include developing a design for ships to be powered by green ammonia; testing of large batteries for its heavy-duty haul trucks; and trialling green ammonia to power locomotives and hydrogen fuel cells in its drill rigs. **PE**

FIRST PUBLISHED 14 APRIL 2021

Abu Dhabi taps Asian ties for hydrogen push

GREEN HYDROGEN / Flurry of agreements lays foundation for expanding historic energy collaboration in the fledgling market / **Clare Dunkley**

A trio of pacts last month between state-owned Adnoc and Asia's leading energy consumers to cooperate in the development of the fast-growing hydrogen industry illustrated the speed with which even the world's leading oil parastatals are being forced to bend to international decarbonisation pressures.

Deals were struck in quick succession with South Korea, Malaysia and India—as the Emirati behemoth scrambles to lock in a dominant role in the changing energy landscape. And in early April, the UAE's federal authorities signed an accord with Japan, which is emerging as the regional pioneer in hydrogen use, to collaborate on the development of an international supply chain for the fuel.

That Tokyo should choose the UAE for its first intergovernmental hydrogen deal builds on a mutual, albeit asymmetric, energy dependence dating back decades between the chronically energy-poor Asian giant and the federation's oil-rich main emirate. Adnoc typically sells over a quarter of its crude to Japan (the world's fourth-largest importer), to which it is the second-largest supplier, and until 2019, Japanese power companies had bought the Emirati giant's entire LNG production, while Inpex and other Japanese parastatals own extensive upstream equity stakes.

The evolution of the partnership to adapt to the buyer's changing energy preferences appears inevitable.

Japan's Carbon Neutral 2050 plan calls for the energy mix to incorporate 3mn t/yr of hydrogen by end-decade—by which time the government intends to have in place an international blue ammonia supply chain—and 20mn t/yr by mid-century.

The revolution under way in the international energy industry strikes Adnoc at a propitious time in its 50-year history. Since the oil price crash in the middle of last decade, the company has cast off its conservative reputation to undertake a



3mn t/yr
Japan's target for
hydrogen in generation
mix by 2030

series of financial and operational innovations—including an early venture into carbon capture, utilisation and storage (CCUS) that will expand sixfold to 5mn t/yr under ambitious blue hydrogen plans unveiled in January.

However, there is also a sense of urgency: the potential for any country with sufficient endowment of renewable resources to produce green hydrogen at scale theoretically implies a multitude of possible long-term competitors while, more

pressingly, other regional oil producers are likewise aiming to corner the fledgling blue market. Saudi Aramco shipped a pilot blue ammonia cargo to Japan in September. The memorandum of cooperation between the UAE's Ministry of Energy and Infrastructure and Japan's Ministry of Economy, Trade and Industry calls for a feasibility study on a similar arrangement—and builds on a deal between the latter and Adnoc, inked three months earlier.

One innovation by the company under its newly dynamic iteration was the expansion of its upstream equity partnerships beyond Japan to other key Asian consuming countries through allocating their state energy firms stakes in the emirate's main oilfield concessions in the second half of last decade. The strategy is now bearing unforeseen fruit. On 4 March, one of the firms, South Korea's GS Energy, formally pledged to explore collaboration opportunities in blue hydrogen production and its export as ammonia, while a vaguer energy sector co-operation agreement two weeks later with New Delhi (an upstream stakeholder since 2018) singled out hydrogen as an area for potential joint efforts.

An agreement with Malaysian NOC Petronas on 10 March to collaborate in both hydrogen and CCUS differed in being the first between the two state companies—reflective of Malaysia being only a minor crude importer. Its context, amid a wider cooperation pact including upstream hydrocarbons, is also a reminder that Abu Dhabi still has lucrative oil and gas sector investment opportunities with which to tempt prospective partners. Two licences from Adnoc's second international bid round remain unawarded, while further upstream auctions are planned. Petronas also signed a pact with Abu Dhabi's original clean energy pioneer, state-owned Masdar, to examine joint investment in green hydrogen and renewables. **PE**

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“The Humber has to be at the centre of the UK’s decarbonisation strategy”
Wheeler,
SSE Thermal

Equinor and SSE to develop first H₂ power station

BLUE HYDROGEN / Humber development of 100pc hydrogen power plant and CCS-equipped gas-fired power plant would share CO₂ storage infrastructure / Tom Young

Norwegian state-owned energy company Equinor and UK utility SSE Thermal are to jointly develop both a 100pc hydrogen power plant and a gas-fired power plant equipped with carbon capture and storage (CCS) in the UK’s Humber region.

The Keadby Hydrogen power station—which has a peak hydrogen demand of 1,800MW—would be fed by blue hydrogen that is created from natural gas at the site, but could accept any form of hydrogen in the future. The 900MW Keadby 3 power station would be a more conventional combined-cycle gas turbine design but equipped with CCS technology.

The two plants would share infrastructure to transport CO₂ to the proposed Endurance storage site in the North Sea, for which the Northern Endurance Partnership (NEP) consortium was formed to develop last October.

If the two power plant projects go ahead they would replace older and more carbon-intensive generation on the grid, according to Stephen Wheeler, managing director of SSE Thermal. “As the largest and most carbon-intensive industrial cluster, the Humber has to be at the centre of the UK’s decarbonisation strategy,” he says.

The Humber region emits 12mn t/yr of CO₂ which is more than 3pc of the UK’s 354mn t total in 2019.

Both plants are in the development phase, and FID will depend on the policy frameworks set by the government in the

coming months. The UK is expected to announce its national hydrogen strategy later this year.

If it goes ahead, Keadby 3 alone could meet nearly 15pc of the government’s target to remove and store 10mn t/yr of CO₂ by 2030. And Keadby Hydrogen would consume a third of the UK national target for 5GW of low-carbon hydrogen production by the same date.

Multiple projects

CCS and hydrogen are likely to be key to the UK meeting its goal of net-zero emissions by 2050, according to Grete Tveit, senior vice president for low-carbon solutions at Equinor. “We believe that hydrogen and CCS will be vital technologies for reaching net-zero emissions in sectors that are hard to abate,” she says.

Equinor is already developing a 600MW project in the Humber region called H2H Saltend that would reform natural gas into hydrogen and share the same infrastructure as the Keadby plants for transportation and storage.

Equinor is one of the six companies that form the NEP, which has the goal of developing the offshore CO₂ infrastructure in the North Sea.

The NEP—also comprising operator BP, Italy’s Eni, the UK’s National Grid, Shell and Total—won funding from the UK government’s £171mn (\$235mn) Industrial Decarbonisation Challenge last month.

The Norwegian firm is also involved in various other projects that have already received some initial funding from government.

The proposal from Equinor and SSE lays out an attractive package for Zero Carbon Humber to be in Track 1 of the government’s CCS scheme, Stuart Hazeldine, professor of CCS at the University of Edinburgh, tells *Transition Economist*. “But it is still dependent on the Endurance storage site being developed,” he says.

Also dependent on that storage site being developed would be the CCUS proposition being progressed at Net Zero Teesside. Scotland’s Acorn Project—also in the running to be on the first track of the government’s CCS scheme—is likely to be cheaper and quicker to develop and has access to multiple secure storage sites.

Multiple projects will be needed eventually, Hazeldine adds. “All the projects are needed to achieve the UK’s decarbonisation objectives, so the question for the government is how to move ahead with the first ones while keeping the others in play,” he says.

Equinor and SSE have worked together on several projects, including the development of an offshore wind farm at Dogger Bank.

Equinor is also participating in Norway’s Northern Lights project, which has received Norway’s first licence to capture and store CO₂ on the Norwegian continental shelf. **PE**

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The Japan-South Korea hydrogen sweepstakes

CONSUMPTION / Both energy-poor countries are expected to be importing blue and green hydrogen in volume by 2028-30 / **Vincent Lauerman**

Energy-poor and land-constrained Japan and South Korea are widely viewed as the greatest prizes in the low-carbon hydrogen export sweepstakes. Since 2017, they have both released roadmaps to develop hydrogen economies to counter domestic greenhouse gas (GHG) emissions and produce hydrogen-related technologies and equipment for export. Japan and South Korea are expected to be importing low-carbon hydrogen—the blue and green varieties—in volume by 2028 to 2030.

To date, Japanese entities have signed a number of deals with foreign governments and companies to get the low-carbon hydrogen ball rolling, whereas the South Korean government appears to be taking a more systematic approach to sourcing the fuel from abroad.

The Korean Ministry of Trade, Industry and Energy is conducting a feasibility study of at least six countries—Australia, Canada, Indonesia, Saudi Arabia and the UAE have been cited in the press—as it is planning to at least initially source low-carbon hydrogen from a single country as a means to maximize economies of scale and make the fuel economically competitive with fossil fuels as quickly as possible.

That being said, Japan and South Korea both appear to be eyeing low-carbon hydrogen imports from countries in which they already have established and substantial energy relations, with

Australia, Saudi Arabia and the UAE the most likely winners based on pilot projects and cooperation agreements signed to date.

Saudi Arabia

In mid-November, Saudi Energy Minister Prince Abdulaziz bin Salman said the Kingdom had set its sights on being the largest exporter of low-carbon hydrogen in the world, after long being the largest exporter of oil.



In September, Saudi Aramco and the Institute of Energy Economics Japan, in partnership with Saudi Basic Industries Corp. (Sabic, now wholly-owned by Aramco), in a pilot project spanning the full supply chain, produced and shipped the world's first cargo of blue ammonia—converted from blue hydrogen, as shipping raw hydrogen by sea remains a work in progress—to Japan for low-carbon power production.

And near the end of March, Aramco announced it had signed a memorandum of understanding with Japan's largest refiner, Eneos Corporation, to undertake a feasibility study for a low-carbon hydrogen and ammonia supply chain between the two countries.

Despite making a number of other moves since last summer to support its ambitious hydrogen goal, including laying the groundwork for strategic alliances with China and Germany—leading technological powers and potential hydrogen import markets—the Kingdom has yet to cut any deals with South Korean entities for the potential export of low-carbon hydrogen.

UAE

Of the three front-runners, the UAE is the only one to have made hydrogen agreements with both Japan and South Korea, and it has done so since the beginning of the year as it has been playing catch-up in an increasingly net-zero emissions energy world.

On 8 April, the UAE signed a hydrogen cooperation agreement with Japan, with the goal of collaborating on low-carbon hydrogen production and to develop an international supply chain. In particular, the memorandum of cooperation between the UAE's Ministry of Energy and Infrastructure and Japan's Ministry of Economy, Trade and Industry (Meti) lays the groundwork for a pilot project to ship blue ammonia between the two countries, much like Saudi Arabia's recently completed pilot project. This agreement builds on one between Abu Dhabi's state-owned oil company, Adnoc, and Meti to cooperate on developing blue ammonia and carbon capture and storage technology.

In early March, Adnoc announced a deal with South Korea's GS Energy to explore collaboration opportunities for blue hydrogen production and its export as blue ammonia.

Australia

In January 2020, the trade ministers of Australia and Japan met in Melbourne and signed a joint statement of hydrogen cooperation whereby the two countries agreed the other would be a key trading partner for hydrogen. This agreement builds on the Hydrogen Energy Supply Chain, a joint world-first pilot project to economically ship blue hydrogen produced from lignite (low quality brown coal) in the southeastern state of Victoria to the port city of Kobe. **PE**

FIRST PUBLISHED 5 MAY 2021

GOO trade can underpin hydrogen markets

STRATEGIES / Development of liquid market for guarantee-of-origin certificates seen as key stepping stone for emerging hydrogen sector / **Stuart Penson**

Trading in guarantee-of-origin (GOO) certificates can play a key role in developing global markets for hydrogen and low-carbon gaseous fuels including biomethane, according to speakers on a gas industry panel in mid-May.

The use of GOO certificates, which are already widely traded in electricity markets, can help to bring standardisation and liquidity to hydrogen markets, enabling industries to internalise the external cost of climate change. The certificates provide evidence to consumers that energy has been generated sustainably. Some 735.1TWh of renewable GOOs were cancelled in 2020, according to the Association of Issuing Bodies.

“GOOs are easily tradeable due to their book-and-claim character. You can trade certificates in the underlying commodities independently of each other, and you can trade them across the Atlantic and Pacific,” says Gunnar Steck, executive adviser on wholesale markets at European gas industry association Eurogas. “And there is already a market infrastructure in Europe.”

Steck says industry needs visibility and a common currency to drive adoption of low-carbon fuels, which will play a major role in decarbonising the economy.

The role of GOOs and other tradeable certificates is potentially “very important” to the development of a hydrogen market, according to Tudor Constantinescu, principal adviser to the director general for energy at the European Commission.

“All these things are now on the table and up for discussion,” he says, noting that more work is needed on methodologies around the measurement of carbon footprints for the various hydrogen production routes on a European and global level.

Steck says the growth of a liquid hydrogen market will require regulators and government to provide a push for demand in the form of targets and carbon pricing.

The development of trade in GOOs for hydrogen would need to interconnect with existing schemes for electricity and gas, and be backed by legislation, according to Torben Brabo, president of industry

“It’s about combining future schemes to provide for electrons from renewables to be converted into hydrogen”

Brabo, Gas Infrastructure Europe

association Gas Infrastructure Europe.

“We need to see how these GOO schemes can be connected across the different energy systems,” he says. He calls for laws enabling GOOs to be traded across the supply chain from renewable power to hydrogen and into storage.

“It’s about combining future schemes to provide for electrons from renewables to be converted into hydrogen,” he says. This could be challenging from a legislative viewpoint, he adds, citing problems with initial legislation around gas GOOs in Denmark.

Legislation on the ownership of hydro-

gen production could also come under scrutiny amid calls from some to allow transmission system operators (TSOs) to own electrolysers, at least in the early stages of the market’s development. This would require changes to unbundling rules in force in the gas sector.

“At the beginning, to foster this hydrogen business, to gain some speed, it would be more than wise to allow infrastructure partners to take part,” says Francisco de la Flor Garcia, director of international organisations at Spain’s Enagas. “When we are starting a business we need to share knowledge, share risk.”

In the longer term, electrolysers could be operated commercially in the way that LNG import terminals are, with companies competing for access.

Brabo calls for flexibility in writing the regulations for the emerging hydrogen market and warns against a “copy and paste” from the gas market.

“Development could be slowed if we are very rigid,” he says. “TSOs could own hydrogen production assets through subsidiaries for an initial period, especially in areas where there are not enough other companies investing in the sector.”

The Commission will “discuss” unbundling rules, Constantinescu says. **PE**



FIRST PUBLISHED 12 MAY 2021

Saudi's \$5bn green hydrogen plant could expand

GREEN HYDROGEN / The plant, the world's largest, will produce 650t/d of green hydrogen from 2025 / **Matt Smith**



Saudi Arabia's Red Sea coast

The developers of Helios Green Fuels' \$5bn green hydrogen development on Saudi Arabia's northern Red Sea coast are already thinking about expansion.

Technology firms Neom and Air Products and Saudi utility Acwa Power signed a deal in July 2020 to build, own and operate the plant. The current plan is to use a 20MW Thyssenkrupp electrolyser—powered by 4GW of renewable energy—to make green hydrogen that will be converted into ammonia.

The intention is to expand, according to Roland Kaepfner, Neom's executive director of hydrogen and green fuels. "We are already thinking about expansion, depending on how fast the market is going to pick up. It just requires an addition of renewable capacity and an expansion of the electrolyser plant," he says.

The consortium will sign financing agreements to fund the project by the end of 2021.

Each of the partners own an equal share in the project, which will obtain nitrogen from the air and produce 1.2mn t/yr of ammonia. Air Products will be the exclusive buyer of the ammonia with rights to shipping and selling it worldwide.

Tenders to build the renewable electricity capacity will precede the financing agreements and will likely be awarded over the next few months.

The project is a sound commercial prospect, and the developers do not envisage any problems concluding financing, Kaepfner adds.

"We don't have feedstock risk, we have the [power] generation within the project, and we have a guaranteed offtake agreement with Air Products," he says.

Helios will produce 650t/d of green hydrogen at less than \$2/kg. Although construction is a technologically complex proposition, each component of the plant is a mature technology.

"I would say the only risk is getting the right operational setup and letting the components talk to each other to perform at an optimum level," says Kaepfner.

The developers chose to ship the green hydrogen in the form of ammonia because of a lack of hydrogen transportation infrastructure and because ammonia is a versatile end-product.

"There's a lack of infrastructure for liquid hydrogen. A pipeline in our case is an option, but you do not build a pipeline in two years from Saudi Arabia to Europe," Kaepfner adds.

Green hydrogen

Air Products will likely reconvert much of the ammonia into green hydrogen for use in trucks and buses, Kaepfner predicts. Such a proposition will be able to compete economically with diesel, he says, and represents a viable option for marine fuel, although it is likely to be too costly to yet be a viable feedstock in fertiliser production.

Helios' location relatively close to the Suez Canal on the main shipping route from Asia to Europe would make it an ideal place for container ships to refuel on green ammonia.

The plant's electricity will be provided 50pc by wind and 50pc by solar, with solar power likely produced at around the recent record low Saudi tender of \$0.0104 kW/h.

Saudi Arabia's Red Sea coast receives

steady winds at night and is sunny most of the year.

However, there will still be times of low power generation. Helios will operate at a capacity factor of 60-70pc and use battery storage as well as being able to ramp up and down production at times of varying renewable generation.

Some of the green ammonia from Helios could be sold for domestic fertiliser production, while entire industries could be remodelled and relocated to move closer to the source of raw materials.

Neom is in talks with various domestic state-controlled corporations such as state-owned petchems firm Sabic, miner Ma'aden and NOC Saudi Aramco about further potential partnerships.

"We are also working on other downstream applications," says Kaepfner. "We will build a hydrogen innovation and development centre to demonstrate some of the technologies around synthetic fuels."

German industrial conglomerate Thyssenkrupp is part of a partnership manufacturing green hydrogen that it hopes will ultimately replace coal in its steel-making furnaces. Yet Europe's renewable capacity limitations and higher production costs will make it tough for such a project to be competitive.

"From a macroeconomic perspective, why would you ship green hydrogen from Chile, Saudi Arabia or Morocco to Europe?" says Kaepfner.

"It would be easier to just shut down the steel plants in Europe and rebuild them at locations where you have cheapest renewable electricity to produce the hydrogen, but this is not what politicians want to hear." **PE**

FIRST PUBLISHED 13 MAY 2021

Imports to compete with EU production

GREEN HYDROGEN / Costs of transport could be outweighed by very low costs of renewable generation in South America, the Middle East and North Africa / **Tom Young**

Green hydrogen produced in South America, the Middle East or North Africa could be delivered to Europe at levels competitive with local production by 2030 or earlier, despite expensive shipping and cracking costs, according to an analysis of various cost comparisons.

At least 50pc of the cost of producing green hydrogen comes from the cost of electricity, meaning desert areas with large amounts of sunshine, land space and wind are well-suited for production.

But transporting hydrogen is much more expensive and dangerous than other fuels such as natural gas, reducing the cost-effectiveness of imports. Although all fuels encounter efficiency losses along the value chain, such losses are particularly acute in the case of hydrogen—sometimes as high as 30pc below the amount of energy in the original electricity input.

There are three key technologies that could be used to transport hydrogen, all with varying levels of efficiency and cost.

The most developed in terms of intercontinental transport is ammonia, which relies on chemical and semi-refrigerated liquefied petroleum gas tankers. These tankers already carry ammonia on existing routes from the Middle East to Europe. Converting hydrogen to ammonia uses 7-18pc of the energy in the hydrogen itself, as does reconversion.

Liquid organic hydrogen carriers (LOHCs) can also be used to transport the fuel. Making an LOHC involves attaching hydrogen molecules to carrier molecules, and then re-extracting pure hydrogen at the destination. LOHCs are similar in form to oil products and can be carried on product tankers. Converting to LOHCs uses 35-45pc of the energy in the hydrogen itself, as does reconversion.

Hydrogen can also be liquefied and transported, just as natural gas is. However, it requires cooling to -253°C —an extremely energy-intensive process. It then requires specially constructed vessels to be transported. Firms such as Japan's Kawasaki Heavy Industries have developed these vessels, but they have yet to reach wide levels of adoption.

There are many uncertainties associat-



Chile's Atacama Desert

ed with all of these cost components, and some—particularly liquid hydrogen—have the potential to dramatically improve in efficiency, and therefore reduce costs, over time.

Cheapest options

However in the near-term, for distances over 1,500km, analysis by the IEA shows LOHC and ammonia transport by ship are currently the cheapest delivery options, and are broadly equivalent in their costs.

The route from Australia to Japan has been the object of several studies on the cost of imported hydrogen as it is viewed as one of the most likely to develop—Japan has over a hundred hydrogen refuelling stations already and is looking to increase imports, while Australia has the land mass and hours of sunshine suitable for production.

Synthesising these studies, the IEA estimates that importing electrolytic hydrogen in 2030 via either LOHC or ammonia will have a delivered cost after reconversion of \$5.50/kg, cheaper than forecast

domestic production of \$6.50/kg. (The price is as high as \$7/kg using a liquid hydrogen shipping process.) Within this calculation, the cost of production accounts for around \$3.80/kg.

But a separate peer-reviewed study focused on Chile and carried out by the Chilean Solar and Energy Innovation Committee estimated that green hydrogen could be produced much more cheaply than this—for \$2.20/kg currently and \$1.67/kg by 2025.

Saudi Arabia is also developing a project on the Red Sea that aims to produce hydrogen at a cost of less than \$2/kg. Analysis by the IEA estimates that the cost of delivering and converting to the industrial sector by ship is around \$4.20/kg via both LOHC and ammonia.

This means hydrogen could be delivered to Europe at less than \$6/kg, including reconversion. This is the same cost that EU Hydrogen Council assumes for the early 2020s in its Path to Hydrogen Competitiveness report.

The Hydrogen Council says in its 2021 insights report that international distribution and reconversion costs might fall to \$2-3/kg by 2030 if the liquid hydrogen shipping market develops rapidly, implying that delivered costs in Europe could potentially fall as low as \$4/kg by that date.

Analysis carried out by Aurora Energy Research found that green hydrogen produced in Morocco could even be cost-competitive with domestically produced blue hydrogen in 2030.

Aurora also found that domestic green hydrogen production supply is unlikely to be sufficient to meet demand in Europe, providing further economic support for imports.

But domestic green hydrogen production will still be incentivised in the EU, however low the costs elsewhere might be, Aurora commercial associate Alan Jabbour tells *Hydrogen Economist*.

“Europe will want a guaranteed supply of green hydrogen to kick-start demand,” he says. “There is also a security of supply argument, and many of the factors around shipping are still uncertain.” **PE**

FIRST PUBLISHED 27 MAY 2021

Providence eyes hydrogen growth

GREEN HYDROGEN / Group aims to finance a pipeline of hydrogen technology initiatives and applications across the value chain / **Tom Young**

Leading Australian ESG investment firm Providence Asset Group (PAG) joined CEO-led coalition the Hydrogen Council last year.

The firm has a pedigree of investing in the clean technology sector and, following the publication of Australia's National Hydrogen Strategy in 2019, wanted to expand into the hydrogen sector.

The Australian strategy aims to advance pilot schemes, build demonstration scale hydrogen hubs and develop supply chains.

Hydrogen Economist talks to Alan Yu, chief investment officer at PAG, about how the firm hopes to help finance developments.

Tell us broadly what PAG is doing in the hydrogen space?

Yu: PAG has a ten-year agreement with the University of New South Wales, one of the leading research organisations in Australia. In 2020, we founded the Hydrogen Energy Research Centre together with them to support the development of hydrogen. It is a ten-year agreement with an initial \$5mn of investment from PAG.

The focus is basically on building a pipeline of hydrogen technology initiatives and applications across the value chain from storage to energy portability, fuel-cell technology, hydrogen testing and certification, and transport.

We believe we can make a large impact in the development of hydrogen products both in the consumer and small business market and also up to utility scale.

Are there any products to come out of that yet?

Yu: Yes, we have developed a product called LAVO. We see it as the world's first household energy storage system. It uses metal hydride technology to store hydrogen for the equivalent of up to 60kWh of electricity.

We are providing early-stage venture capital for the technology and using our expertise to identify how it can be brought to market. It is scaleable, and we are developing a utility-scale version called LAVO-HEOS that will help cater for the future of green hydrogen transport domestically, and the export of green hydrogen from Australia to countries such as Japan, South Korea and Germany. At the end of this year, we will roll out the first commercial prototype, and we think

the technology will be fully commercially viable from 2022.

So you are trying to bridge that gap between innovative technology and the marketplace?

Yu: Our expertise lies in identifying industry needs, bringing that to the university and then finding a combined solution. It is a problem solving, reverse-engineering approach between the academic and commercial worlds. That enables us to fast-track the process to bring campus-leading research and innovation towards commercial reality.

Will you look for other small firms to take equity investments in if they have the right technologies?

Yu: It will be a mix of both options. Predominantly, we have a unique partnership with the University of New South Wales, and we have first refusal on a lot of unique technologies being developed there. But also, we are open to other startups with unique technologies—for instance, we invested in a smart energy software company called Evergen with an initial \$4mn investment to support the development of AI-intelligence software to integrate with small-scale hydrogen batteries.

We hear a lot about comparisons between hydrogen and the renewables sector. Do you see costs coming down in the same way?

Yu: We think the demand side is not an issue. On a global level lots of countries are rolling out hydrogen strategies, and places like Germany have committed €9bn (\$10.9bn) to build out the infrastructure and get projects off the ground.

The economics of scale is going to drive costs down aggressively just as we have seen with solar in the past 15 years. Research from Bloomberg recently suggested the costs will fall by 90pc over the next ten years. I have an even more bullish view that costs could reduce to that level over the next five years. **PE**



Alan Yu

“The focus is basically on building a pipeline of hydrogen technology initiatives and applications”

FIRST PUBLISHED 4 JUNE 2021



Saudi Arabia

HYDROGEN ECONOMIST

Trucks offer a market for hydrogen

GREEN HYDROGEN / US firm is partner in the Saudi Arabian project, which will produce 650t/d of green hydrogen from 2025 / **Matt Smith**

Industrial gas company Air Products is betting on a shift towards low-carbon transport as part of national emissions reductions strategies to spur bus and truck companies to add hydrogen-powered vehicles to their fleets—despite the additional fuel costs.

The New York-listed firm is an equal partner in Saudi Arabia's \$5bn Helios Green Fuels hydrogen project along with state-owned Neom and the kingdom's Acwa Power, having signed a deal in July 2020 to build, own and operate the plant.

Air Products is also the exclusive buyer of the hydrogen, which it will convert into 1.2mn t/yr of ammonia, shipping and selling it worldwide. The \$67bn company will invest a further \$2bn in the project's downstream infrastructure.

Air Products will reconvert the ammonia into hydrogen for use as fuel by large trucks and buses, delivering the gas to transport refuelling stations. The company in April opened a hydrogen fuelling station at its industrial gases facility in South Korea's Ulsan City, and has been involved in around 250 hydrogen fuelling projects globally.

"The interest level is incredible since we announced this project," says Simon Moore, vice president for investor relations, corporate relations and sustainability at Air Products. "We see great opportunities around the world. There are other exciting markets for hydrogen, other transportation markets—trains, planes. Then there's the industrial side ... but for

this project we're focused on the bus and truck market."

Helios will use 20 MW of Thyssenkrupp electrolyzers, powered by renewable electricity, to make green hydrogen. Its annual production will be enough to supply 20,000 buses, while around 3mn buses worldwide are in operation today. As such, Moore is confident there will be sufficient demand from bus operators for hydrogen-powered vehicles—and with it, his green hydrogen—by the time the Neom plant is operational.

"When we talk about hydrogen in the future, it is about lower-carbon hydrogen. Hydrogen for transportation markets, for industrial applications—broadening it from the more classic use of hydrogen in the refining industry," he says.

Helios' partners have yet to decide how to fund the plant, but project financing is a possibility, Moore explains.

'Game changer'

"This is not just a game changer for Air Products, it is a game changer for the world," he says. "There isn't anything else like this, but while it is innovative in the sense of bringing all this together and in terms of scale... it is not a technology test programme. Each of the steps are well-proven."

Although green hydrogen will remain expensive compared with grey and blue hydrogen and other fuels, Moore says cost will not be a decisive factor in shaping adoption of hydrogen-powered buses and trucks.

"The world clearly wants to move towards a lower-carbon footprint for transportation fuels. When you want to move in that direction, the politicians are reflecting the will of the people in general," he says.

"We are not as focused on a direct economic comparison between say diesel and carbon-free hydrogen. It should come as no surprise to anybody to say carbon-free hydrogen is going to be more expensive than grey hydrogen."

Moore cited his company's lengthy experience in transporting hydrogen, noting the huge expense in doing so over medium and long distances as well as the costs and inefficiencies in liquefying and distributing the gas. Such factors led Air Products, which is also building Saudi's \$11.5bn Jazan gasification plant, to decide on converting the Neom project's hydrogen into ammonia.

"Obviously it does take a cost to turn hydrogen into ammonia, [but] based on its molecular properties it is much easier than transporting hydrogen," says Moore. "It is really just a way to move those hydrogen molecules around. There's a robust global network to transport ammonia."

Gasification, hydrogen and carbon capture are Air Products' three key growth pillars, he says.

"We see a tremendous opportunity in part for the transportation market, but also to just to decarbonise existing hydrogen markets as well," he adds. **PE**

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Compression a potential shipping option

FREIGHT / Ships could be better-suited to short-haul voyages, offering market scalability, according to Global Energy Ventures / **Vincent Lauerman**

Ships carrying compressed hydrogen could help the nascent international hydrogen market grow by offering scalability, according to shipping firm Global Energy Ventures (GEV).

Hydrogen is expensive and difficult to ship, and no single technology has yet emerged as the most cost-effective solution. Most hydrogen shipped internationally is first converted into ammonia, but this method has high reconversion costs, and some technical issues still remain in attaining hydrogen pure enough for use in proton-exchange membrane fuel cells.

Liquefied hydrogen is often viewed as the natural successor to ammonia as export markets build and the costs of the technology come down.

But one of the advantages of compressed hydrogen (C-H₂) ships is that their capacities can be scaled to the size of the market, whereas liquefied hydrogen ships must be relatively large to be economic, according to Martin Carolan, GEV managing director, tells *Hydrogen Economist*.

“A key advantage of C-H₂ ships is scalability, allowing the size of ship to grow with market size,” Carolan tells *Hydrogen Economist*.

GEV, in collaboration with Vancouver-based Ballard Power Systems, is developing a C-H₂ ship to transport low-carbon hydrogen. GEV’s shipping method has lower projected costs than moving liquefied hydrogen for routes up to 4,500 nautical miles (8,300km), according to Carolan.

Shipping liquefied hydrogen

In a report released last year titled Path to hydrogen competitiveness: A cost perspective, industry association the Hydrogen Council indicated liquefied



“A key advantage of C-H₂ ships is scalability, allowing the size of ship to grow with market size”

Carolan, GEV

hydrogen was the most likely method for raw hydrogen to be economically shipped by sea in the future. To support this viewpoint, the council provided an outlook for landed costs for liquefied hydrogen in probable major import markets, provided by global consultancy McKinsey & Company.

Hydrogen shipping routes laid out by McKinsey tend to be relatively short haul, since the cost of shipping liquefied hydrogen remains high in 2030—about five times the cost of shipping LNG on an energy-equivalent basis. For example, the consultancy is projecting the cost of shipping liquefied hydrogen from Saudi Arabia to Japan to be \$1.70/kg in 2030, assuming sufficient scale, compared with a hypothetical cost of about \$15/kg for this route in 2020.

At least two companies are presently working on constructing commercial-scale bulk carriers for liquefied hydrogen—Japan’s Kawasaki Heavy Industries (KHI) and Korea Shipbuilding & Offshore Engineering. KHI completed a small-scale prototype, the Suiso Frontier,

in December 2019. The ship is undergoing sea trials, with the first voyage from Japan to Australia and back—around 9,000 km—expected in the coming months.

Shipping compressed hydrogen

In contrast, GEV’s C-H₂ ship design is relatively straightforward and, as a result, should have significantly lower operating losses and fixed capital costs, according to Carolan. It has fewer stages in the supply chain than liquefaction and ammonia conversion, most of its technologies are readily available and the design has minimal technical hurdles.

What hurdles there are should be surmounted in the next 18-24 months, he

adds. This has allowed the company to obtain approval in principle from US regulatory body the American Bureau of Shipping for the vessel’s containment system, based on a cargo capacity of 2,000t of hydrogen, in mid-March.

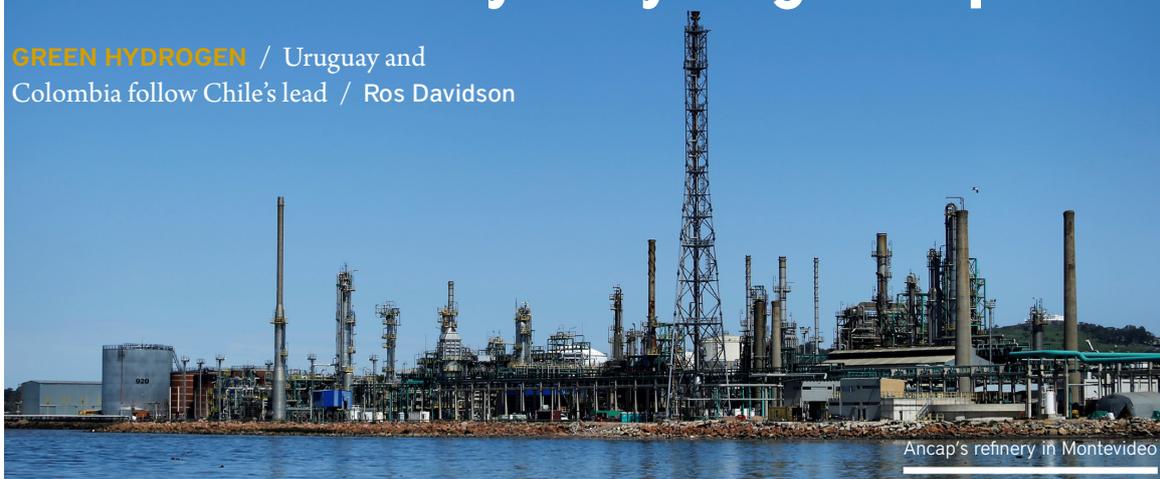
GEV released results of a scoping study at the beginning of March showing a C-H₂ ship of this size should have a substantial cost advantage over its competitors for voyages of 2,000 nautical miles, and a modest one at 4,000 nautical miles. The economics of compressed hydrogen ships are negatively impacted for longer-haul voyages because of the amount of hydrogen they can transport for a given vessel size, with liquefied hydrogen ships able to carry three times more cargo and ammonia ones five times more.

On 7 June, GEV announced plans to launch a smaller scale C-H₂ ship, with a capacity of 430t, by the middle of this decade compared with late this decade for its first large-scale vessel. The company believes its ship design should be competitive for short-to-medium length voyages for hydrogen cargoes up to 4,000t. **PE**

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Latin America eyes hydrogen exports

GREEN HYDROGEN / Uruguay and Colombia follow Chile's lead / Ros Davidson



Ancap's refinery in Montevideo

Major companies in Latin America are eyeing hydrogen's potential as a key component in their countries' clean energy transitions and as a source of export revenue, according to a panel at the Hydrogen Americas Summit 2021.

Colombia-based Grupo Energia Bogota (GEB), a utility holding company with close to \$10bn in investments across Central and South America, is seeking partners in hydrogen projects, GEB president Juan Ricardo Ortega told the panel. "We are looking to grow and we are looking [at] the future of hydrogen," he said.

He noted that developing domestic consumption in Colombia will not be as easy as in Chile, where the mining industry could prove to be a significant source of demand. Chile is the hydrogen leader in Latin America—its large H2Chile private partnership is promoting the clean fuel as part of the energy transition. Chile aims to be carbon neutral by 2050, with hydrogen a key component.

Colombia has the wind and solar potential needed to produce green hydrogen. Capacity could be as high as 20-25GW, with much of it in the north of the country. Most of that power could be used to produce green hydrogen for export, suggested Ortega.

GEB expects to see export demand for hydrogen begin to develop in about 2030. "We are looking at the possibility [that] Colombia could be one of the countries to supply the world," he continued.

Blue hydrogen is also a possibility in the north of Colombia, with its large reserves of natural gas. "We can see that as

one of the likely future exports of Colombia," said Ortega, noting a coal port in the region could be used for exporting hydrogen.

Alejandro Stipanovic, president of Uruguay's state oil company Ancap, told the panel his firm also sees hydrogen as crucial to its transition to a low-carbon and sustainable energy future, complementing the move into biofuels. "Hydrogen is the way we see Ancap in the future," he said.

Ancap views offshore wind as having great potential for producing green hydrogen, and the oil company will—in the long-term—look for partners in that sector.

The company is working on bids for offshore wind development in three different blocks off Uruguay's coast. Ancap also has several decades of experience in the production, purification, storage and use of hydrogen at le Teja, Uruguay's sole oil refinery.

Uneconomical

A dilemma for such companies is what happens when oil refineries become uneconomical in the energy transition, Stipanovic said. "After the [oil] refineries are gone, we see Ancap as strong, as an agent or partner in the offshore production and export of green hydrogen," he said.

He suggested the company's storage capacity could also ultimately be used for hydrogen, whether at its refinery or at its La Tablada distribution plant.

The Uruguayan government is finishing a roadmap for the H2U hydrogen project, with a view to producing hydrogen for

local consumption and exports to international markets such as in Europe and Asia, he noted. Private investment with government support is being sought for onshore and offshore hydrogen. The onshore production would use the existing grid and green power sources, and would entail new dedicated facilities. Offshore, the facilities would also be new.

Under the government plan, private investors are building a pilot green hydrogen project with the potential to produce 360kg/d of hydrogen. A charging station is being installed in Montevideo. Production at facilities will be ramped up to meet local demand in the second stage, to be followed by large-scale exports, he said.

Ad Astra Energy and Environmental Services, a subsidiary of US rocket propulsion company Ad Astra Rocket Company, is working on renewable energy and green hydrogen storage and use in Costa Rica.

CEO Franklin Chang Diaz noted his company has developed Central America's first hydrogen transportation ecosystem project to power a fuel cell bus imported from the US using a system based on solar power. In 2018, the then-new president Carlos Alvarado Quesada and his cabinet travelled in the bus to the presidential inauguration.

Currently, Ad Astra is commercially expanding by building a second dispenser. The company will then move to full-scale regional implementation. It is exploring opportunities for projects in Bolivia, Chile, Colombia, Costa Rica, Honduras and Mexico. **PE**

FIRST PUBLISHED 15 JUNE 2021

Avangrid sets sights on US green hydrogen push

GREEN HYDROGEN / US unit proposes multiple projects as it looks to leverage its portfolio of wind and solar generation / **Gregor Macdonald**

The US Department of Energy's (DOE) Hydrogen Earthshot initiative is not even two months old and Spanish utility Iberdrola's US division Avangrid has answered the call with a robust suite of potential projects.

The DOE's aim is to spin up a constellation of ideas, and to seed the landscape with shared proposals. Its RFI (request for information) seeks ultimately to trigger a hydrogen ecosystem, lower the cost of electrolysis, and Avangrid's existing asset base appears ripe for exploration of these goals.

Avangrid identified its gas utility assets in the state of Connecticut, for example, as a prime candidate to deploy a 20MW electrolyser and hydrogen storage facility, capable of producing 2.9mn kg of hydrogen per year. Avangrid noted the imminent construction of a new, offshore wind industry from which it could draw in the future.

"Our Connecticut-focused response acknowledges the state's innovative procurement of large-scale offshore wind power and considers its potential as a unique resource for green hydrogen production, while also providing information on scenarios where solar PV and/or grid-based power contribute to the production of hydrogen for the region," says Avangrid spokesman Adam Gaber.

Avangrid owns eight electric and gas utilities in the US northeast, and a much broader portfolio of renewables across the US. Gaber also notes that Avangrid "supports the Federal administration's goal of achieving \$1/kg green hydrogen by 2030, but other than that goal, neither Avangrid nor the DOE has implied any specific timeline for the deployment of hydrogen infrastructure."

Green aspiration

The production of economic green hydrogen in the US remains an aspiration. The US is engaging in a well-known sector-development model that it has used previously in other industries including renewable energy and aerospace. Responses to its RFI will eventually become candidates for future funding rounds, creating a development pipeline.



More broadly, however, the US has lagged severely in both self-investment and also research and development spending for decades, but suddenly has a new appetite for government seeded innovation. Even Republicans, who have been ideologically against any innovation model not exclusive to the private sector, have found themselves more open to the Biden administration's efforts.

Still, even in a robust innovation landscape, the US may find that it will need a European style carbon market to make progress more fluid.

One of the more notable responses from Avangrid focuses on the potential for an electrolyser facility that would start to decarbonise its Klamath Falls, Oregon natural gas driven cogeneration plant, operated by its renewables division. "The Klamath plant is unique in that it is used to balance the intermittency of the energy generated by Avangrid's 1,300MW fleet of wind and solar projects in the Northwest," says Gaber.

The basic idea is that a new electrolyser would act as a source of demand load that could run whenever needed to prevent the curtailment of surplus clean generation from wind and solar. Avangrid is unique in that it's the only renewables

operator that operates its own independent balancing authority.

The EIA says that in 2020, renewables collectively became the second largest source of electricity in the US, nipping past coal and nuclear, and now behind only natural gas. The green hydrogen potential is rich, therefore, from the standpoint of clean power supply.

What's needed however is the propagation of industrial, demand side projects that get the learning rate going in electrolysis. Avangrid also has its eye on this area, with a response for a very large scale electrolyser facility in Corpus Christi, Texas that would convert state generated wind power into both green hydrogen and ammonia. **PE**

"Avangrid supports the Federal administration's goal of achieving \$1/kg green hydrogen by 2030"
Gaber, Avangrid

FIRST PUBLISHED 30 JULY 2021



British Columbia's comprehensive H₂ plan

STRATEGY / Province commits to financial incentives and direct support for hydrogen industry and eyes potential as exporter / **Vincent Lauerman, Calgary**

The British Columbia (BC) government has released a hydrogen strategy to scale up production of both the green and blue varieties in the province, promote local hydrogen hubs and consumption, and ultimately establish a thriving low-carbon hydrogen export industry.

The strategy commits to ramping up financial incentives and direct support to promote investment in the BC's fledgling hydrogen industry, outlining 63 actions to be undertaken by the provincial government over the short (2020-25), medium (2025-30) and long (2030-50) term.

"This is the first comprehensive hydrogen strategy of any province in Canada," David Layzell, co-founder and energy systems architect at Canadian not-for-profit The Transition Accelerator, tells *Hydrogen Economist*. "Other provinces, such as Alberta, have released roadmaps or background papers to promote hydrogen in their provinces, but BC has now provided steps and targets."

The key short-term actions by the BC government will be on the regulatory front, the strategy says. "Many regulatory changes are needed to lay the foundation for a successful hydrogen industry in the province," says Duncan McPherson, a partner at Bennett Jones, an international law firm based in Calgary.

"The two most important changes are

regulations to allow carbon capture and storage to open the door for blue hydrogen production in the province, and regulations to provide water rights to green hydrogen projects since electrolyzers need a lot of water."

To support greater consumption of low-carbon hydrogen in BC, the strategy states the province will consider expanding incentives under the Zero-Emission Vehicles Act (ZEVA) from light-duty vehicles (LDVs) to medium- and heavy-duty ones. "I'm very supportive of the BC government expanding ZEVA to heavier transport, since these vehicles require a relatively small number of fuelling stations," says Layzell. "In contrast, I am less supportive of the original focus of this programme. Battery electric vehicles (BEVs) tend to be substantially more economic for LDV than hydrogen fuel cell-powered ones."

Export potential

BC may be blessed with abundant hydro and wind resources for the production of green hydrogen, but that does not mean it can economically produce it for future export markets—a fact the province acknowledges in its strategy. BC Hydro rates are too high to make cost-effective green hydrogen, even with discounts under its discounted Clean Industry and Innovation Rate.

As a result, the strategy suggests "alternative electricity rate designs" might be adopted sometime in the 2025-30 period to support green hydrogen producers in BC. Layzell says its "very possible" that price subsidies such as these could in the future lead to trade actions by countries with their own plans for low-carbon hydrogen production, such as the US.

"On a more fundamental basis, the question to ask is whether hydropower should even be used to produce green hydrogen in BC, especially since it takes a lot of power to produce," says Layzell. "It may be better used powering BEVs, and the greater electrification of the economy as a whole, to achieve net zero."

On the other hand, Layzell and McPherson both agree BC has world-class natural gas reserves and geological storage potential and, over time, should be able to produce huge amounts of blue hydrogen for the provincial and export markets.

"At the same time, BC—and the same goes for Alberta and Quebec—will be able to leverage existing infrastructure to ship low-carbon hydrogen to international markets," McPherson tells *Hydrogen Economist*. "The pipelines and rail and ports provide these provinces with a great advantage. Vancouver and Montreal are Canada's two largest port cities." **PE**

FIRST PUBLISHED 28 JULY 2021

China plans massive clean H₂ deployment – BNEF

STRATEGY / Rapid growth in electrolyser market as Chinese companies race to show compliance with government's carbon-neutrality target / **Ros Davidson**

Large industrial companies in China are planning massive clean hydrogen projects on a scale unheard of anywhere else in the world—and to an extent that surprised the authors of research firm BloombergNEF's newly released H₂ 2021 *Hydrogen Market Outlook*.

"Deployments and plans for deployments in China are going through the roof," says Martin Tengler, BNEF's lead hydrogen analyst. The surprise regarding China's rise to prominence is because the country has no national hydrogen policy, although it does have a 2060 net-neutrality target, announced on 22 September 2020.

"What is happening in China right now is revolutionary for clean hydrogen," says Tengler. "Chinese companies are racing to show their compliance with the country's carbon-neutrality target, pushing the market for electrolysers to be at least nine times bigger in 2022 than in 2020."

Chinese executives want to stay in the government's good books, meaning it is not a question of market forces, he adds.

Tengler says one implication of China's rapid rise to become the world leader in clean hydrogen is that there is no one-size-fits-all policy to drive growth. Incentives and a \$100/t carbon price may be needed for broad hydrogen adoption in some market economies, but China's unprecedented growth has been fuelled by little more than a yet-to-be legislated commitment to carbon-neutrality.

China has been the world leader in hydrogen for some years, but electrolysers were mostly powered by grid-based electricity, which has been based heavily on coal. The deployment of renewable ener-

China



gy in China has been rapid and recent.

The country's demand for clean hydrogen comes from big steel and national oil and fossil fuel-based chemicals firms—especially state-owned enterprises—says the reports, which focuses on clean hydrogen, whether green or from fossil fuels with carbon capture and storage.

As of mid-July, at least six large Chinese companies had more aggressive CO₂ reduction plans than the central government, and five of these six companies plan to adopt hydrogen as a feedstock in chemical reactions.

Three of these firms drive the majority of BNEF's forecast for electrolyser deployment in Asia-Pacific: energy company Baofeng; Sinopec, the world's largest oil refiner; and Baowu, the world's largest steel producer.

To give an idea of the scale of the trend in China, Tengler noted that Baofeng is building a 150MW electrolysis project to come online by the end of 2021. The world's current largest electrolyser is Air Liquide's 20MW project in Quebec, commissioned in January.

Electrolyser surge

Globally, electrolyser shipments are set to double in 2021 and quadruple in 2022, when they will reach 1.8-2.5GW. China should account for 60-63pc of 2022 global installations, BNEF says.

By 2030, cumulative global installations could exceed 40GW based on developer disclosures. Alkaline electrolysers will continue to dominate the market due to better economics, with an 80pc share in 2022, says BNEF.

Although more than 40 countries have now published a hydrogen strategy or are developing one, the market for clean hydrogen is still far from certain because of its cost and a lack of incentives, says Tengler.

He adds that the world will need to see CO₂ prices of at least \$100/t by 2030 to incentivise much hydrogen adoption. The EU has a price of only about half that today, and BNEF forecasts only three markets will reach \$100 before 2030: Canada, where there is a national carbon price; the EU, with its emissions trading; and the UK, which will basically follow the EU's lead.

"It is no surprise then that the vast majority of announced large-scale demand-side clean hydrogen projects come from these regions," he says.

Apart from higher carbon prices, so-called 'contracts for difference' could be a form of support for hydrogen, the BNEF report says. These pay project developers the difference between the actual carbon price and the carbon needed to justify their investment. A carbon border adjustment mechanism should also help developers of low-carbon projects. The EU, which is pioneering both approaches, will act as a laboratory for policies stimulating hydrogen demand, according to the report.

BNEF forecasts that clean hydrogen will cost below \$2/kg in much of the developed world by 2030. It could outcompete coal in steel production by around 2027 in Canada and around 2028 in the EU and the UK, according to the report. **PE**

FIRST PUBLISHED 10 AUGUST 2021

Abu Dhabi eyes new hydrogen frontiers

BLUE HYDROGEN / Two recently announced ventures will see the emirate's increasing production of the gas being deployed in steel and fertiliser industries / **Clare Dunkley**

Amid the string of announcements over the past eight months asserting Abu Dhabi's arrival on the international hydrogen stage, two in a day in early August stood out as affirming intent both to decarbonise domestic industries and exploit other countries' desire to do so.

First, state-owned duo Abu Dhabi National Energy Company (Taqa) and Emirates Steel agreed to collaborate on the Middle East's first use of hydrogen in steelmaking—a notoriously hard-to-decarbonise process. Meanwhile, state-owned Adnoc advanced plans to become a core provider of the vast volumes of hydrogen required to fulfil Japan's emissions-reduction ambitions by exporting a first cargo of blue ammonia to Japanese firm Itochu.

Finding a way to green steel production is increasingly recognised as key for global industrial decarbonisation: the sector accounts for around 7-9pc of the world's direct emissions from fossil fuels, which are used to heat furnaces and also as a reagent in the manufacturing process.

This makes decarbonising the sector especially challenging and costly. However, Abu Dhabi and the wider Middle East have an advantage in their dependence primarily on the direct reduced iron (DRI) production method rather than the blast furnace technology predominant in Europe and elsewhere—a consequence of the region's ample gas reserves.

It is easier and cheaper to substitute hydrogen into the DRI process than into the blast furnace process. Emirates Steel's 3.5mn t/yr integrated iron and steel plant encompasses 2mn t/yr of DRI capacity. Meanwhile, Taqa agreed in July to co-develop a 2GW green hydrogen complex at the local Kizad industrial area.

Their joint announcement on 3 August was short on detail—the description “green steel” is used to denote varying reductions in carbon intensity, and precisely where in the production process the green hydrogen would be deployed was unstated—with project design said to be already underway.

At present, low-carbon steel is considerably more costly to manufacture,

“We aim to create a wide range of ammonia value chains for existing industrial applications as well as future energy use”
Tanaka, Itochu



whether using carbon capture and storage (CCS) or green hydrogen. But falling prices for the latter—as renewable power becomes cheaper, electrolyzers are scaled up and global demand increases thanks to carbon pricing—will make the cleaner option increasingly cost-competitive. Abu Dhabi's government is also aware of its diminishing gas reserves.

Greener steel than most

The Emirates Steel plant is already greener than most. It became the first in the world to deploy CSS at scale in 2016, with 800,000t/yr of CO₂ emitted during the production process sequestered underground at the Ruwais downstream hub.

In May, Adnoc announced plans for a near sixfold expansion of CCS capacity, to 5mn t/yr, as part of a joint venture (JV) project with government holding company ADQ to produce 1mn t/yr of blue ammonia using hydrogen derived from its nearby refining and petrochemicals operations. Fertigllobe—a recently created JV between Adnoc and Netherlands-based fertiliser company OCI—joined the scheme the following month.

Meanwhile, Adnoc has signed a series

of agreements with various firms to cooperate on fuel ammonia production and the development of an international hydrogen supply chain, signalling intent to expand into the hydrogen sector.

Adnoc and Itochu recently announced that a first blue ammonia shipment of unspecified size had been sold to the Japanese company ‘at an attractive premium’ to its grey cousin for use in fertiliser applications. The chemical was manufactured at Fertigllobe's Fertil plant at Ruwais, whose 1.2mn t/yr of ammonia production will be incrementally transformed from grey to blue through retrofitting CCS.

Tokyo's hopes of decarbonising power generation and its 130mn t/yr of potential steel production rest heavily on hydrogen imports—a position its existing Mid-East Gulf oil suppliers, primarily the UAE and Saudi Arabia, are well-placed to exploit.

“Starting with this trial... we aim to create a wide range of ammonia value chains for existing industrial applications as well as future energy use,” says Itochu executive officer Masaya Tanaka.

Adnoc's counterpart and rival Saudi Aramco shipped a pilot blue ammonia cargo to Japan last year. **PE**

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Blue hydrogen economics strong in near-term

BLUE HYDROGEN / Panellists agree it will take time and incentives to reduce cost of green hydrogen to a level where it is competitive with the blue variety / **Tom Young**

Blue hydrogen can be produced for as little as \$1/kg in the US, but this is still twice the cost of grey hydrogen, meaning government intervention will be vital to spur production of the cleaner fuel.

Blue hydrogen will always cost more to produce than grey hydrogen because of the additional carbon capture and storage processes required, Richard Mew, director at consultancy Koyos Resources, told the First Element conference.

“The general consensus is that you need a cost of producing hydrogen at \$1.5/kg in order for significant carbon abatement to occur,” he said, noting this was possible only in jurisdictions with low gas prices.

“With blue hydrogen that is almost achievable in the US and possibly the Middle East—but in Europe, Russia and China there will need to be [government intervention] brought into the equation.”

There are two key forms of intervention: grants and government-backed loans as incentives for blue hydrogen production; and financial penalties, such as carbon pricing, as disincentives for more carbon-intensive hydrogen production.

“Quite often it is a mixture of the two,” said Mew. “With the renewable obligations certificates (ROCs) that were given to green producers of electricity they could sell them on to more polluting producers.”

ROCs for hydrogen have been promoted as a desired policy incentive by various reports from industry-aligned groups.

Currently, the differential between green and blue hydrogen costs is even greater than that for blue and grey, according to Al Cook, executive vice president for exploration and production at Norwegian energy company

Equinor, speaking at the Offshore Europe conference.

“Green hydrogen is probably two to three times more expensive than blue, so in terms of like-for-like we see blue hydrogen as having quite a large advantage at the moment,” he said.

Equinor is nevertheless pursuing green hydrogen projects—most notably the NorthH2 project in the Netherlands—alongside its blue hydrogen developments in the UK, Germany and the US because it sees green hydrogen as the ultimate fuel for the hydrogen economy.

“With blue hydrogen you can open up the pipelines, the consumers, the users of hydrogen as a fuel, and then as the prices of green hydrogen come down so green hydrogen can replace it,” he said.

Switching incentives

The International Renewable Energy Agency believes the switch from blue to green could happen as soon as 2030 with the right government incentives, according to deputy director Roland Roesch.

“Electrolyser costs have fallen 60pc since 2010, and our work finds that they

can become 40pc cheaper in the short term and 80pc cheaper in the long term, with the deployment foreseen in national strategies bringing costs down below \$2/kg,” he said.

This would still be more than the production costs of

blue hydrogen in some jurisdictions, but if countries were to introduce further incentives—such as contracts for difference—then that cost gap could be bridged.

The EU’s hydrogen strategy has focused largely on green hydrogen, but the US and UK are putting a greater focus on near-term blue hydrogen development. **PE**

\$1/kg

Approximated
cost of US
blue hydrogen
production

Offshore wind can unlock US green hydrogen potential – BNOW

GREEN HYDROGEN / Gulf of Mexico and California seen as potential hotspots for projects coupling the two technologies / **Ros Davidson, San Francisco**

Offshore wind power is the key to unlocking the potential of the US green hydrogen market, according to Ross Gould, vice president for supply chain development at US membership organisation Business Network for Offshore Wind (BNOW).

“For hydrogen to reach its potential, it must connect to offshore wind,” says Gould, also staff lead for BNOW’s green hydrogen working group.

US demand for hydrogen could reach 41mn t/yr by 2050, almost four times current demand, according to the Department of Energy’s National Renewable Energy Laboratory (NREL).

Interest in pairing offshore wind with electrolyzers to produce green hydrogen in the US is increasing fast. BNOW’s working group, launched in August, has eight members. Its inaugural meeting was attended by about 50 participants, says Gould.

Offshore-wind-to-hydrogen is promising in the US because of land constraints for onshore wind and solar, says Gould. It could be especially cost-effective in the Gulf of Mexico (GOM) and in California, he adds.

Electricity is already cheap in the GOM, so offshore wind could be most efficiently paired with hydrogen used for transport, heavy industry and the fossil fuel sector. In the last of these, the hydrogen could power exploration and drilling, reducing greenhouse gas emissions. California, with its rigorous climate goals, also has potential.

But in the near-term, most offshore wind development in the US is expected to take place off the East Coast. The northeast—a region that stretches from Maine to Virginia—is often called the “Saudi Arabia of offshore wind”, says Gould.

Developers are starting to come forward with offshore-wind-to-hydrogen



“For hydrogen to reach its potential, it must connect to offshore wind”

Gould, BNOW

projects in the US. An early-mover is a 10MW green hydrogen pilot with utility South Jersey Industries planned for the proposed Atlantic Shores offshore wind project off New Jersey. The 1.51GW wind project, a 50/50 partnership between Shell New Energies and France’s EDF Renewables, is to start construction in 2024.

Emissions reduction

Separately, Avangrid, part of Spanish utility Iberdrola, has unveiled proposals for green hydrogen projects in Connecticut, New York, Maine, Oregon and the Gulf Coast. Avangrid is a partner in several offshore wind projects off the US northeast. The firm says the proposal for a 20MW electrolyser and hydrogen storage for its Connecticut gas and electric utilities could be “potentially powered by renewable energy from offshore wind

and supplemented by additional solar or grid-based renewable electricity.” It is estimated the project could produce roughly 2.9mn kg/yr of hydrogen, yielding an annual emissions reduction of approximately 25,000t of CO₂.

The US is several years behind Europe in developing offshore wind, but the market is expected to grow fast from the 42MW currently installed. The Biden administration has given the expansion of offshore wind high priority.

The US offshore wind project pipeline grew by 24pc in 2020 compared with the previous year, with more than 35.3GW in various stages of development, according to NREL. By 2030, the US could be the third-largest global region for installed offshore wind after China and the UK, says research firm BloombergNEF.

Projects coupling green hydrogen and offshore wind are gaining traction in Europe, with developers including Denmark’s Orsted, Norway’s Equinor and Germany’s RWE involved.

H2 Energy Europe of Switzerland is planning a 1GW green hydrogen production site near Esbjerg in Denmark to be operational in 2024. The electricity would come from one or more offshore wind farms located nearby in the North Sea. **PE**

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UAE targets \$1.3/kg blue hydrogen

BLUE HYDROGEN / Country should target green and blue hydrogen production as it looks to develop market, says Qamar Energy report / **Tom Young**

The UAE could produce blue hydrogen for as little as \$1.3/kg based on IEA estimates for gas prices, according to a report from consultancy Qamar Energy.

This is at the low end of the range calculated by the thinktank Energy Transitions Committee for the possible cost of producing blue hydrogen today. The range is \$1.3-2.9/kg depending on the cost of natural gas and carbon capture and storage infrastructure. The Hydrogen Council estimates the cost of producing blue hydrogen in Europe at \$2.1/kg today, falling to about \$1.8/kg by 2030.

Storage costs

The UAE has access to cheap natural gas, and the report notes that its CO₂ storage costs are likely to be lower than most locations.

“Storage sites are formed by giant, well-characterised and high-quality reservoirs, with very effective overlying seals, in shallow water or open desert, and in close proximity to the sites of CO₂ production,” says the report, titled *The UAE’s Role in the Global Hydrogen Economy*.

The UAE should pursue green and blue hydrogen projects to develop a competitive advantage in both technologies, it adds, noting blue hydrogen will be easier to scale up initially.

Emirati NOC Adnoc announced plans in May to build a blue ammonia project in Abu Dhabi, and has signed agreements to explore export opportunities with Japanese and South Korean firms.

The firm has also announced plans to build a green ammonia project in Abu Dhabi powered by an 800MW solar power plant.

Abu Dhabi’s Supreme Petroleum Council—which is in charge of energy

“Storage sites are formed by giant, well-characterised and high-quality reservoirs”
Qamar Energy report

policy—has mandated Adnoc to become a ‘hydrogen leader’. The UAE government is working on a national hydrogen strategy, which is still in the initial stages.

As a first step to scaling up, a guaranteed level of domestic demand needs to be created, according to the Qamar Energy report.

“The most promising existing blue hydrogen opportunities in the UAE are for

steel, direct-reduced iron, oil refining and fertilisers,” it says, adding that production can be located in clusters near to these sources of industry demand.

In green hydrogen, low renewable costs also make the region an attractive area for green hydrogen production. The 2GW Al-Dhafra photovoltaic plant agreed a power-purchase agreement in 2020 at 1.35¢/kWh—one of the lowest rates anywhere in the world. The report expects around at least 50GW of renewable capacity to be added between now and 2035.

The UAE’s established status as an energy and international business hub also makes it a good candidate for the development of hydrogen infrastructure, the report notes.

UAE firms have signed five major collaboration deals this year, including a recent UK-UAE deal to develop 2GW of blue hydrogen. **PE**

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Egypt turns to green desalination

GREEN HYDROGEN / Cairo hopes renewables-based water purification could both narrow the domestic deficit and enable it to realise its green hydrogen ambitions / **Clare Dunkley**

Egypt is preparing to tender for the construction of a network of desalination plants powered by renewables to address an acute shortage of fresh water and provide feedstock for green hydrogen production.

The country's sovereign wealth fund is seeking partners to invest about \$2.5bn to build, own and operate 17 desalination facilities powered by solar and other renewable resources with a combined capacity of 2.8mn m³/d by 2025.

Egypt is taking advice and technical support from the European Bank for Reconstruction and Development and the World Bank's International Finance Corporation, with the first tenders—for some 1mn m³/d—due in early 2022.

Prime Minister Mostafa Madbouly also recently met with executives from Norway's Scatec Solar, the UAE's Metito Water Treatment and local firm Orascom Construction to discuss clean desalination.

Saudi government-affiliated developer Acwa Power—which installed 120MW of the power online at Egypt's giant Benban solar park and is developing another 200MW at nearby Kom Ombo—appears certain to play a major role. The company, the home market of which has the largest desalination capacity in the world, signed a memorandum of understanding (MoU) in February 2020 with Egypt's Ministry of Housing, Utilities & Urban Communities—which is spearheading the desalination drive—and the Minis-

try of Electricity and Renewable Energy to conduct feasibility studies for a series of desalination projects using either solar or wind power.

Acwa is also among those setting the global pace for conventionally powered purification—winning a local project in May last year at a then-world record levelised water cost of \$0.413/m³.

Green hydrogen feedstock

Egypt's move to address its water scarcity comes as it develops a green hydrogen strategy despite its potential to produce blue hydrogen from its natural gas reserves. Until the technology is developed to directly split seawater at a viable cost, green hydrogen production in freshwater-scarce states such as Egypt will require desalination prior to electrolysis.

Germany's Siemens signed an MoU with state power group Egyptian Electricity Holding Company "to jointly explore opportunities for hydrogen production and export in Egypt", including the installation of a pilot 100-200MW electrolyser.

Separately, Germany's Man Energy Solutions has agreed with TAQA Power to implement a pilot project producing green hydrogen for use in buses.

The North African nation's freshwater deficit is widening and is estimated at around 110bn m³/yr. That leaves per capita supply, sourced mainly from the Nile with the addition of groundwater and delta rainfall, at barely half the

World Bank's 1,000m³/yr water poverty threshold.

Desalination is typically considered a rich-country solution to water scarcity—widely adopted by the wealthy Mid-East Gulf states but unsuited to similarly arid but cash-strapped Cairo. It is economically unviable for use in agriculture, which accounts for more than 75pc of Egypt's water consumption due to a history of poor water management and myopic policy.

However, with energy and technology costs coming down, and given the urgency of the situation, the government has been slowly rolling out gas-powered desalination to provide potable water to coastal cities far from the Nile. Total installed capacity stands at around 830,000m³/d, and plans were announced in July 2020 to install 47 plants pumping out 2.44mn m³/yr of purified water by mid-decade, without specifying the energy source.

Egypt has a comfortable power capacity cushion following a dramatic response to a sudden shortfall that emerged at the turn of the last decade.

Only around 10pc of the country's capacity is derived from renewables, but development of such projects has accelerated over the past two years in pursuit of a target to derive 42pc of electricity from renewables by 2035—an achievable goal given Egypt's plentiful supplies of sun, wind and available land. The authorities are looking to use some of the additional clean power capacity to fuel the desalination ramp-up. **PE**

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Ineos targets UK clean hydrogen market with Runcorn upgrade

BLUE HYDROGEN / Investment will allow sales into transport and power generation sectors / **Stuart Penson**

Chemicals group Ineos has unveiled plans to upgrade operations at its Runcorn complex in northwest England to produce hydrogen of adequate quality to use in transport and power generation from 2023.

The project will cost “tens of millions of pounds” and forms part of the €2bn (\$2.33bn) investment in clean hydrogen production at sites across Europe announced by Ineos in mid-October.

The Runcorn site, operated by Ineos subsidiary Inovyn, produces around 7,000t/yr of hydrogen as a byproduct of electrolyser-based production of chloralkali.

The upgrade will see the installation of facilities to purify and compress the hydrogen to a high-enough quality to be used in fuel cells for distribution to fuelling stations across the UK.

“We are committed to supporting hydrogen in the UK, and this is the first step,” Inovyn UK country and operations manager Nigel Bouckley told *Hydrogen Economist* on the sidelines of an event at the Runcorn site.

Ineos is funding the project itself and is not receiving government support, Bouckley says, urging the UK government to support the roll-out of hydrogen infrastructure.

“We need the government to put in place the middle part of the jigsaw,” he says, noting that Germany has 110 hydrogen filling stations compared with 11 in the UK.

Hydrogen production at Runcorn has the potential to provide low-carbon fuel to power over 1,000 buses or 2,000 trucks, according to Ineos.

Inovyn has in place some memorandums of understanding to supply hydrogen to end-users, including a Liverpool bus operator, but has not yet signed official offtake agreements, storage projects



manager Richard Stevenson tells *Hydrogen Economist*.

Inovyn produces clean hydrogen at Runcorn from its chloralkali process using a bipolar electrolyser with a capacity of 185MW.

The electrolyser draws on the national power grid, which has a diverse energy mix and therefore does not qualify as green hydrogen. Inovyn will look at renewable power solutions for Runcorn at a later stage, the company says.

Hydrogen has been produced at the Runcorn site for over a century, and Inovyn is keen to leverage its expertise to enter the emerging hydrogen market.

“Inovyn is in a unique position to reaffirm its expertise in hydrogen production and electrolysis,” says Inovyn CEO Geir Tuft.

The company’s move to enter the UK clean hydrogen market comes as its plans to develop hydrogen storage as part of

the HyNet North West low-carbon cluster consortium gather momentum. The UK government chose HyNet as one of the “track one” projects that will receive government funding and become operational by 2026.

Inovyn’s part of the HyNet project includes 19 salt caverns earmarked for hydrogen storage, with a capacity of 1.3TWh.

“Track one status has given us a seat at the table with the Treasury,” Stevenson says. “We need investment to start next year. We are not looking for government handouts, but we do need the right business framework.”

He says a contracts-for-difference mechanism could offer the right solution. “Having that framework will allow us to invest,” he says.

The Inovyn storage project could be partially online by 2026 to coincide with other elements of HyNet, although would not be fully operational by that point. **PE**

“We are committed to supporting hydrogen in the UK, and this is the first step”
Bouckley, Inovyn

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East Coast and HyNet win CCS funding

BLUE HYDROGEN / Both projects feature blue hydrogen in their plans to develop low-carbon clusters to cut industry emissions / **Tom Young**

The UK's HyNet North West and East Coast Cluster have been confirmed as the first low-carbon clusters that will receive state funding to develop blue hydrogen projects.

As part of a ten-point plan outlined in December, the UK announced it would provide £1bn (\$1.4bn) to support the development of industrial carbon capture, utilisation and storage (CCUS) clusters around the country. Two industrial clusters will be established by the mid-2020s in the first phase, with a further two by 2030 in the second. Combined, the two phases will capture 10mn t CO₂/yr from industry and inject them into storage sites.

Seven industrial clusters were originally competing for funding: Scotland's Acorn CCS; Zero Carbon Humber; Net Zero Teesside; HyNet North West; the South Wales Industrial Cluster; a Southampton cluster; and the Neptune project in Lincolnshire.

Earlier this year, Zero Carbon Humber and Net Zero Teesside joined forces to form the East Coast Cluster.

"I am...confirming that the HyNet and East Coast clusters have been confirmed as track one clusters for the mid-2020s and will be taken forward into...negotiations," energy and climate change minister Greg Hands said in parliament.

"If the clusters represent value for money for the consumer and the tax-

"The project will enable our manufacturing sector across the region to decarbonise" Parkin, HyNet

payer then, subject to final decisions of ministers, they will receive support under the government's CCUS programme," he added.

The Acorn cluster has been designated a reserve cluster if a back-up is needed. Hands said the government would continue to engage with Acorn in the second phase of its sequencing process—which will take place later in the decade—and that it remained committed to enabling 10mn t/yr of storage by 2030. This would require at least four, and likely five, of the clusters to be operational.

The HyNet project will feature a blue hydrogen facility that aims to produce the fuel from 2025 and will initially use the hydrogen for local industrial and mobility purposes. The partners hope to bring a second facility online two years later.

"From as soon as 2025, the project will enable our manufacturing sector

across the region to decarbonise, as well as providing the opportunity to transition the way we travel and how we heat our homes," says HyNet project director David Parkin.

BP is planning a 1GW blue hydrogen project as part of the Net Zero Teesside development. It has already signed offtake agreements with four firms. Meanwhile, SSE Thermal is also progressing plans with Equinor for the world's first major 100pc hydrogen-fired power station at Keadby in Lincolnshire, as well as a large-scale hydrogen storage facility at Aldbrough on the East Yorkshire coast—both of which could plug into the East Coast Cluster.

The East Coast Cluster could deliver 70pc of the UK's hydrogen target to have 5GW of low-carbon hydrogen by 2030, the partners say.

"We are delighted that the East Coast Cluster has been selected and we will look forward to delivering our project, removing up to 50pc of the UK's industrial cluster CO₂ emissions, creating tens of thousands of jobs and establishing the UK as a leader in the energy transition," says Andy Lane of the Northern Endurance Partnership (NEP).

The NEP is a consortium of members from the Net Zero Teesside and Zero Carbon Humber clusters and the National Grid, which will handle the transport and storage of CO₂ under the North Sea. **PE**



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Cummins looks to hydrogen ICE engines

DEMAND / Internal combustion engines powered by hydrogen regarded as interim decarbonisation solution / **Vincent Lauerman**

Automakers are announcing plans to develop hydrogen-fuelled internal combustion engines (ICEs) for vehicles as an interim decarbonisation measure, given the time it will take to improve the economics of high-cost hydrogen fuel cell engines.

Indiana-based Cummins, a leading maker of diesel engines, revealed a plan in September to develop medium-duty 6.7-litre and heavy-duty 15-litre engines fuelled by hydrogen following preliminary testing over the summer.

British heavy machinery maker JCB is also researching hydrogen-fuelled ICE engines for its excavators and other vehicles, while Toyota is planning to launch hydrogen combustion versions of the Prius and Corolla by 2025. In support of this move, the Japanese auto-giant recently unveiled an experimental hydrogen-powered ICE Corolla racecar.

To better understand the advantages and disadvantages of hydrogen-fuelled ICE engines, *Hydrogen Economist* contacted Jon Mills, director of external communications at Cummins. He canvassed business and technical experts in the engine and new power divisions of the company to best answer our questions.

What are the major advantages of hydrogen-fuelled ICE engines over hydrogen fuel cell engines at the present time?

Cummins: We believe a range of alternative power solutions will be necessary to effectively help our customers transition to a carbon-neutral world in the coming years. The hydrogen engine may provide a more immediately affordable and adaptable solution in terms of vehicle installation, as it would allow OEMs to continue using familiar mechanical drivelines rather than converting entire fleets to battery electric or fuel cell electric all at once.

Will ICE engines require substantial modifications to run hydrogen instead?

Cummins: Converting current diesel or natural gas engine platforms to operate on hydrogen with substantial modifica-



“We believe a range of alternative power solutions will be necessary to effectively help our customers transition”
Cummins

tions is certainly possible, but our initial test work demonstrated that achieving the goal of zero CO₂ with current engines comes with a significant loss of performance and efficiency. To avoid that compromise, Cummins’s H2-ICE programme will be based on our next generation of gaseous-fuelled engine platforms designed from the outset with higher power density and without increasing weight or packaging space.

Assuming there are substantial modifications, what are they?

Cummins: Our hydrogen engine development programme will focus on a next generation fuel injection system—higher in-cylinder combustion efficiency, friction reduction and improved thermal management—to a degree not possible with today’s engine designs.

Will these modifications add significant cost to hydrogen-fuelled ICE engines compared with diesel-powered engines?

Cummins: Technologies to achieve zero emissions currently come at a higher cost than a diesel engine. In terms of the hydrogen engine, that incremental cost is somewhat mitigated as it can be manufactured at existing engine facilities and

is based on a proven platform and engine support network.

In terms of operating cost, while hydrogen fuel costs remain elevated today, the number of renewable hydrogen production projects underway means we expect to see meaningful reductions in this price over time.

This will help us bring hydrogen down the cost curve, which is a critical component of achieving cost parity for both the hydrogen internal combustion engine and fuel cell powertrains, and for encouraging technology adoption.

What are the major disadvantages of hydrogen-fuelled ICE engines over hydrogen fuel cell engines at the present time?

Cummins: Hydrogen-fuelled ICE engines remove carbon emissions, but are not zero emission. The levels of NOx and particulate matter emitted from a hydrogen engine will be reduced below that of today’s most stringent regulations, but it is not zero. The end-goal is zero emissions which will only be achieved with battery electric or fuel cell electric, coupled with renewable energy sources. Our work to date also shows that fuel cell has a higher efficiency capability when compared with hydrogen ICE, and this will be important for fuel consumption and associated running costs. **PE**

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An offshore wind-to-hydrogen future

GREEN HYDROGEN / German government launches tender to explore potential of pairing offshore wind with electrolysis in country's northern exclusive economic zone / **Gregor Macdonald**

Germany's Federal Ministry for Economic Affairs and Energy has put out a tender call for the testing and development of offshore wind paired with hydrogen electrolysis.

The tender is part of the country's existing Wind Energy at Sea Act, which contains provisions to conduct experiments in technologies not part of the energy system in the country's exclusive economic zone, a broad swathe of offshore real estate in Germany's north.

While admitting the development timeline for any scalable offshore production of green hydrogen is in the very earliest stages, the ministry envisions such capabilities as being beneficial—if not critical—to the future of German industry.

"When we think about expanding renewable energy capacity, we are starting to find some constraints in onshore capacity," says Brais Armino Franco of AtlantHy, a Madrid based hydrogen consultancy. "We also need to think about the value an asset provides to a system. So, offshore provides more stability of supply. We can predict it much better."

Franco says the main factor in Germany's exploration of offshore wind-to-hydrogen is the stark difference in capacity factors between onshore and offshore wind. According to his analysis of data from the Global Wind Atlas online platform, Germany's average onshore capacity factor comes in at roughly 30pc. But its offshore capacity factor is at 60pc. "If we want to get the same amount of energy, we need two wind turbines on land for every one offshore," says Franco.

In the US, onshore capacity factors are

higher by comparison, coming in just below 36pc nationally in 2020, according to the EIA. But in select states such as Texas—a giant of global wind production—the capacity factor is closer to 40pc.

Earlier this year, Berlin awarded funding to German energy company Siemens for the exploration of offshore wind-to-hydrogen feasibility via a project called H2Mare. The current tender will set auctions in early 2022, based on qualitative criteria. Winners will be then granted offshore acreage and become eligible for funding, which the ministry has set at an initial €50mn (\$57.8mn).

Payback

While the cost of electrolysis remains high everywhere, it is an axiom within grid economics that the more you can maximise generation or utilisation in any 24-hour period, the more favourable the payback timelines. And high-cost electrolyzers are no exception. Run them a full day rather than a half day, and their economic returns will shift dramatically.

Franco is a co-author of a recent white paper that studied the addition of hydrogen pipelines to deliver offshore-produced hydrogen and found costs could be €5.35/kg but as low as €2.17/kg "if EU support reaches its targets".

The paper, Assessment of offloading pathways for wind-powered offshore hydrogen production, pays special attention to the capacity factor differences of offshore wind, showing that in all modelled scenarios the levelised cost of hydrogen drops meaningfully as one slides up from the mid-40s to the mid-60s in

capacity factors. Franco points out that the IEA, in its recent Global Hydrogen Review, forecasts that offshore hydrogen production will eventually be cheaper than onshore.

Research firm BloombergNEF also estimates that offshore hydrogen will start at roughly \$7/kg in 2025 but drop to \$1/kg by 2050. The current high costs, with the potential for dramatic cost declines, have implications for most national initiatives from China to India to the US, which have all recently jumped into the hydrogen game with big aspirational goals.

The US may be a unique case, in this regard. High capacity factors in states such as Texas, and even higher factors in states such as Iowa and Oklahoma, may tempt the US Department of Energy (DOE) to start siting electrolysis in these areas. But the US is also kicking off a new offshore wind industry. And companies such as Avangrid have already responded to a DOE call for projects, noting that new offshore generation could be utilised to run near-onshore electrolysis.

The real test will come when electrolysis starts to emerge from a subsidised domain and has to stand on its own. The sensitivity analysis in the Franco white paper suggests offshore capacity factors will be an immovable structural advantage. If so, offshore wind-to-hydrogen is inevitable.

Franco thinks Germany is making the right move. "Germany's choice of offshore is fantastic. There is huge wind capacity there, and much of the territory is only 50m deep, which will allow for rapid deployment." **PE**

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