Future Energy

The technologies shaping the energy transition

From THE EDGE

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Every week in The Edge, Wood Mackenzie's Chairman and Chief Analyst Simon Flowers shares his take on the natural resources industry's biggest stories, how they are likely to evolve and what that means for your business.

The Edge's Future Energy series draws insights from Wood Mackenzie's Energy Transition Service and highlights the technologies shaping the transition away from fossil fuels toward a decarbonised future.

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Future energy: green hydrogen
Could it be a pillar of decarbonisation?

The ambition is net-carbon neutral. The EU, and others, want to get there by 2050, some even sooner. Achieving that goal needs policy, investment and technology. Hydrogen is one of the technology pillars on which hopes to abate climate change rest. To find out more, I chatted to Ben Gallagher, our lead analyst on emerging technologies.

What is the attraction of hydrogen?

It's a super-versatile energy carrier with exceptional energy density (MJ/kg). Today, around 70 million metric tonnes of hydrogen are produced globally, used across an array of sectors – fertiliser, refining, petrochemicals, solar panels and glass manufacturing. In the future, hydrogen will have a huge role to play in decarbonising the global economy, especially in hard-to-decarbonise sectors. But, first, there are a lot of challenges.

How is hydrogen produced today?

The technology is entirely based on fossil fuels. Around 71% is 'grey' hydrogen (steam methane reformation, or SMR) while most of the rest is 'brown' hydrogen (gasification of coal or lignite). These processes have been around for decades. The challenge is dealing with the carbon and high emissions that result. The future for the current technology is all about 'blue' hydrogen, where the production process is paired with carbon capture and storage (CCS). But CCS isn't yet widely commercial and needs scaling up, too.

Grey, brown, blue – what about green hydrogen?

The technology is different, with the hydrogen produced from water by renewables-powered electrolysis. The process is zero carbon and gives very pure hydrogen, whereas grey or brown hydrogen contains impurities. The idea is that green hydrogen piggybacks on the rapid roll-out of renewables in the coming decades. As penetration of intermittent solar and wind generation into power markets rises, system prices will fluctuate and generally should be lower. When there's surplus renewables, prices will drop, becoming cost-effective for green hydrogen. The hydrogen can then be sold or stored until it's needed. Green hydrogen therefore becomes both a form of energy storage and a balancing tool for renewables.

What are the uses?

As well as the sectors hydrogen already sells into, green hydrogen's zero-carbon credentials open a wide range of new ones. Green hydrogen will be critical for difficult-to-decarbonise industries like steel and cement, for blending with methane in gas pipelines (though hydrogen's low volumetric density poses challenges for existing infrastructure), in fuel cells for electric vehicles and many other applications.

And the economic challenges?

Green hydrogen has to compete with SMR hydrogen, which costs between US$1-2/kg without CCS – or 50 cents more when paired with CCS. These are costs that green hydrogen can't even get close to currently. Green hydrogen's economics are particularly sensitive to two factors – power prices and plant utilisation rates. The economics only work on what are unrealistic assumptions today – high load factors (more than 50%) and low electricity prices (below US$30/MWh). But, right now, a green hydrogen plant paired with a renewable source could expect load factors nearer 20%; typically, power purchase agreement prices for renewables are nearer to US$50/MWh globally.

How could green hydrogen become viable?

First, cost reduction – we expect capex to fall by 30-40% by 2030, especially as the manufacturing process for electrolysers moves to automation, unit feedstock costs reduce by 5% and electrolyser efficiency improves by 8%. But those gains still leave green hydrogen well out of the money.

What needs to change?

The big impetus is likely to be policy and societal desire for change. If, as we expect, national and corporate strategies embrace green hydrogen as part of a strategy to decarbonise, it could take off, driving the economic threshold down. That means investment in R&D, improvements in technology, pilot projects with industrial users and adapting to changing power markets as renewables penetration increases. Carbon pricing will be key – we estimate a carbon price of US$40/tonne in 2030 could get green hydrogen on a level with SMR-produced hydrogen paired with CCS.

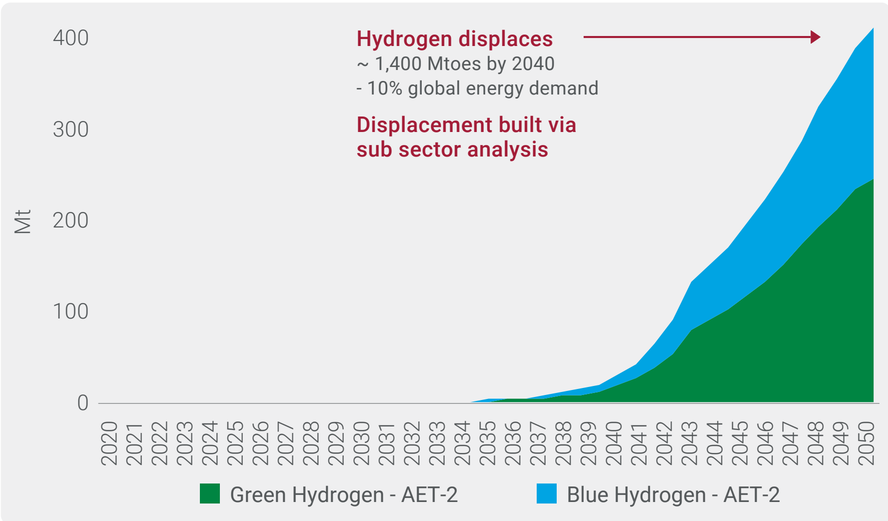
When?

Realistically, it'll be another decade before hydrogen starts to make a meaningful contribution to decarbonisation. Today green hydrogen is tiny, with only around US$365 million invested in 94 MW of capacity, though the pipeline of new projects has quadrupled in less than a year to over 15 GW. That shows the interest the technology is attracting in China, Japan, the US, Europe and Australia, but so far, it's only scratching the surface. If the pieces fall into place it could be huge. We think hydrogen could displace 1400 Mtoe of primary energy demand by 2050 under a 2-degree scenario LINK, 10% of global supply, with green hydrogen the majority of that. Scalable, commercial green hydrogen would answer a lot of questions around global decarbonisation.

And who will invest?

Only a handful of companies have entered the electrolyser market. But rising membership of the Hydrogen Council, formed in 2017, reveals the widespread interest among big players across multiple sectors including automakers (among them BMW, GM and Honda), power and gas utilities (Engie and EDF), engineering (Bosch, Alstom), finance, and oil and gas (Aramco, Shell, BP, Total and Equinor).

Hydrogen deployment under a 2-degree pathway



Blue hydrogen comes when SMR hydrogen is paired with CCS while green hydrogen comes from splitting of water molecules using renewable electricity.

Source: Wood Mackenzie

Future energy: carbon capture & storage
Central to decarbonisation strategies

Shell, Repsol, BP are among those setting bold targets to become net-carbon neutral. Governments, too, will head in that direction. But how to get there? Carbon capture and storage (CCS) is invariably central to the strategy. I asked Ben Gallagher, lead analyst on emerging technologies, about the opportunity and the challenges.

What is CCS?

A method of removing the carbon dioxide (CO2) released in the processing or combustion of hydrocarbons. CCS can be applied in power generation, natural-gas processing, refining, cement, hydrogen reforming and chemicals and other industries. There's now a search underway to use the carbon or embed it in materials – what's called carbon capture utilisation and storage.

Why's there so much interest in CCS?

Few think the global economy can thrive for the next few decades without coal, oil and gas. The world will be emitting carbon for decades yet; the trick will be to capture and store it. Commercial, scaled-up CCS means we can use fossil fuels while greatly reducing CO2 emissions until energy consumption is fully decarbonised. It's going to be hugely important for hard-to-decarbonise sectors like cement and steel.

How is CO_2 captured?

There are four main processes, each with its own complexities. First, pre-combustion. A gas mix of hydrogen and carbon monoxide (CO) is processed converting the CO into CO_2. The CO_2 is then removed using solvents.

Second, post-combustion. Sulphur and nitrogen-based gases and any trace metals need to be removed. The residual flue gas is then heated and treated with solvents, releasing CO_2.

Third, there's oxy-combustion, where enriching the fuel-burning process with oxygen gives a higher concentration of CO_2 in the flue gas. Lastly, there's direct air capture, a nascent technology that removes CO_2 from the atmosphere. It's very energy-intensive but may play a part longer term.

How is the carbon stored?

In the many depleted oil and gas fields around the world, with the CO_2 transported by pipeline. The Global CCS Institute reckons there's almost 400 years' worth of storage capacity at today's level of annual emissions – more than enough to meet the Paris climate targets. Geological stability is among the environmental criteria for this to work. There are also long-shot contenders for storage – such as low-grade coal seams and saline reservoirs.

Could the carbon be used?

Yes – to enhance oil and gas recovery, extending the economic life of a productive reservoir. New concepts being considered include: embedding CO_2 in concrete and other building materials; purifying it for carbonation; transforming it into polyurethanes for use in home furnishings and other materials; and turning it into food products.

What are the challenges?

The idea of CCS has been around for decades, but it still hasn't really got off the ground. We reckon 68 projects have started and terminated, primarily because CCS is very expensive. Costs are difficult to get a handle on because no project is the same, and a lot of technology is proprietary.

Instead we look at 'cost of CO_2 avoided' – the carbon price that makes a project economic. We estimate that a minimum carbon price of US$90/tonne is needed for most applications, about three times today's traded price in Europe. Costs do vary widely – some power projects might make money below US$50/tonne; in difficult-to-decarbonise sectors like steel, it's up to US$120/tonne; and cement up to $194/tonne.

Costs need to come down. R&D will help, as will, in time, scale and a modular, standardised approach. But CCS also needs fiscal support – as with tax credits in the US recently – and it needs access to low-cost finance so investors can generate an adequate return on equity.

How much investment is needed?

Today, it's a tiny part of the decarbonisation story – the 42 million metric tonnes of installed capacity are capable of capturing just 1% of annual global emissions. Most are attached to power plants. We think capacity will double by 2030. As the power sector transitions to renewables, blue hydrogen production makes up an increasing proportion of the CCS development pipeline.

If the world is to get onto a 2-degree pathway, we could need up to 4 billion tonnes of capacity by 2050, 100 times what we have today. Exponential growth will require exponential investment. That will only happen if the incentives are there – high carbon prices, policy support or, most likely, both.

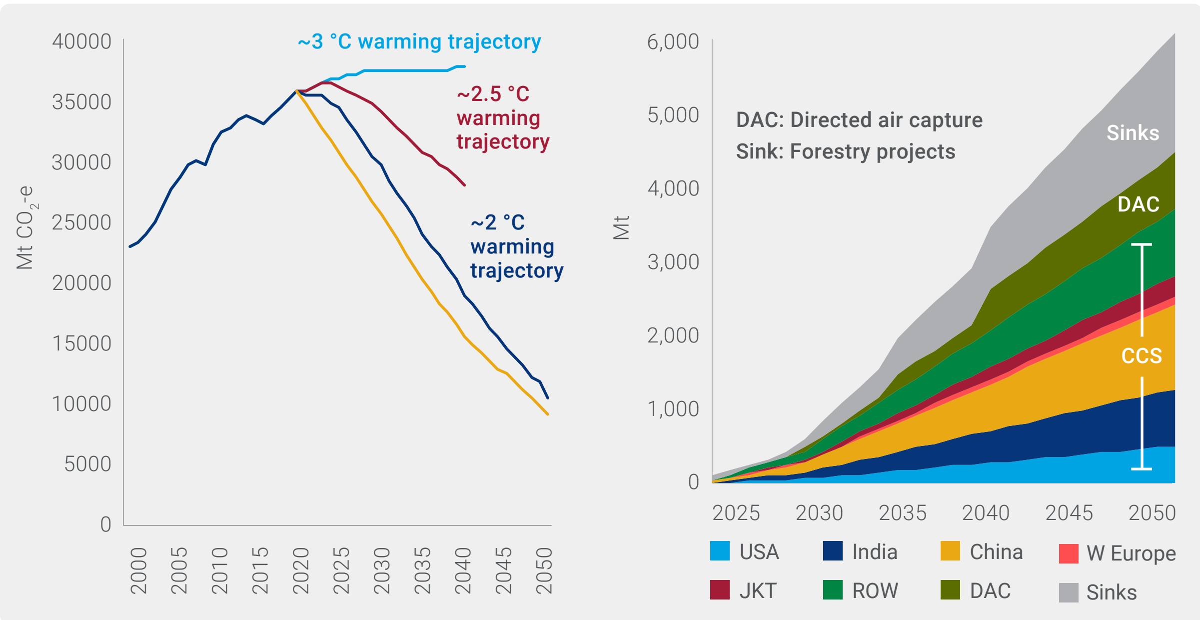
How will Big Oil invest in CCS?

First, storing carbon extracted from high CO2 gas fields – Chevron (Gorgon, Australia) and Equinor (Sleipner and Snovhit, Norway) have projects already in operation.

Second, injecting post-combustion CO2 to enhance oil recovery – Occidental is one of the leading exponents in the Permian.

Thirdly, and a big growth opportunity, is to partner in high-emitting but hard-to-decarbonise sectors. Total has teamed up with Lafarge and Svante in Canada to pilot CO2 capture and reuse from Lafarge's Richmond cement plant in British Columbia.

Global carbon emissions by scenario and CCS capacity to meet AET*-2, WoodMac's 2-degree scenario



*Accelerated Energy Transition (AET)

Source: Wood Mackenzie

Future energy: zero-carbon heating

Could heat pumps displace gas in our homes?

Fifty years ago, natural gas transformed homes with instant heat and hot water. But the days of gas and other fossil fuels dominating domestic fuels may be numbered. Rapidly evolving policy in the EU is searching for technologies to speed up electrification and decarbonisation.

Heat pumps could be part of the answer, binding households once and for all into reducing carbon emissions. Our experts in new energy technologies, Fei Wang and Ben Gallagher, and Murray Douglas, European gas, explained the options.

What is the technology?

Heat pumps are a proven technology, a heating and cooling system that's ready for mass deployment. Two types are suitable for residential or commercial use – air source and ground source. Unlike a combustion boiler, they don't produce heat but work like a fridge, transferring heat from a coil outside the building to a second coil inside using a refrigerant. The process can be reversed for air-conditioning in summer. They run on electricity, ideally zero-carbon renewables.

The big advantage is the heat pump's exceptional energy conversion rate. A modern gas boiler has an efficiency rate of around 80%, with 20% lost in the process. Heat pumps can have 300% efficiency, generating 3kw of thermal energy for every 1 kilowatt consumed.

How big is the opportunity?

Huge. Over one-third of global energy demand is space heating in the residential and commercial sectors, served by a mix of fuels. Gas is the incumbent fuel in Europe (43%) and an important part of the mix in the US (40%), where electricity already has the biggest share (44%); while coal dominates in Poland and China. Oil and LPG are still widely used globally where communities are remote from gas infrastructure.

The penetration of heat pumps into the market today is minuscule. But the opportunity is massive – many multiples of the 20 million systems installed world-wide.

What's holding heat pumps back?

First, the upfront costs of installation. These can be up to US$15,000, about five times the cost of an average gas boiler. Yet the heat pump's higher efficiency doesn't fully compensate over the life of asset. New York state, for instance, has a cash incentive that makes it economical to switch from fuel oil, but it's still not enough to beat gas.

Second, air source pumps, the cheaper of the two, see a decrease in energy efficiency as temperatures drop to sub-zero, though their performance in colder climates is improving. Ground source does work at low temperatures but is more expensive and needs outdoor space to lay the pipe system.

What's the game changer for heat pumps?

All eyes are on European policymakers. The EU's 'Green Deal' aims to accelerate the reduction in carbon emissions from 40% by 2030 to 50% to 55%. That won't be achieved just by pushing coal out of the power mix – it needs to expand into non-power sectors. Some high energy-intensive industries like steel will take longer, so the focus has to be on transportation – and heating.

Residential and commercial space heating accounts for 11% of global emissions and is going to be in the crosshairs. Some European markets have already legislated against gas connections to new homes and commercial premises. The key question is whether heat pumps can make the big breakthrough to displace incumbent fossil fuel-based heating in existing homes. States in the US, including New York and California, are leading policy advocates of heat pumps.

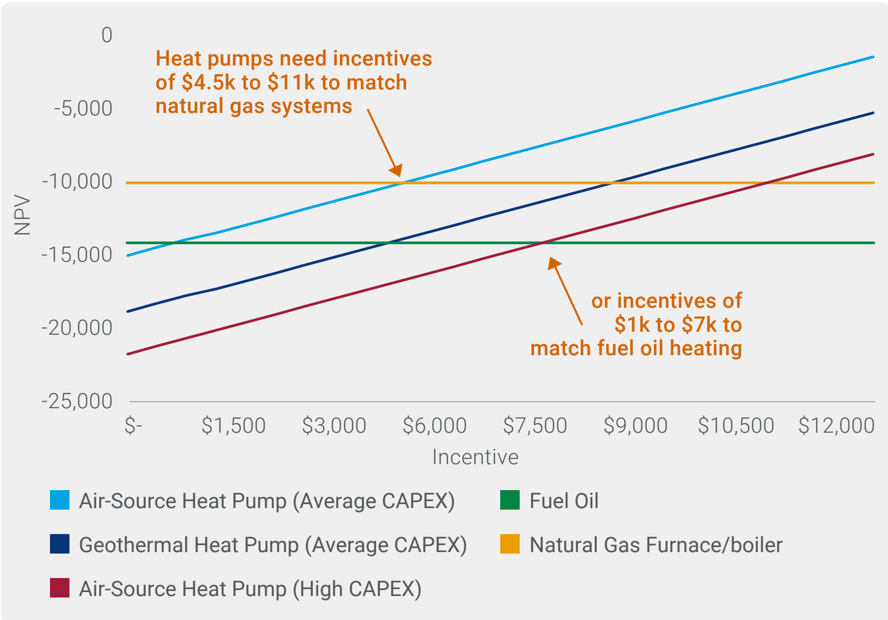
The ability to reverse heat pumps is a real bonus. They can be a one-stop shop to decarbonise both heating and air-conditioning.

What are the implications for future gas and electricity consumption?

The EU's 2030 targets are ambitious and may rely mostly on squeezing coal out of the power market. Heat pumps' economics are just one barrier – the skilled workforce to roll out the systems at scale isn't there yet. It could be that, like electric vehicles, heat pumps go mass market in the 2030s rather than this decade.

The potential loss of gas demand by 2040 could be substantial – we reckon as much as 25% lower in the residential sector to get on the pathway to reach the Green Deal's ultimate goal of net-zero emissions by 2050. That's around 50 bcm, or 10% of total demand, in the EU27 plus UK today. Meanwhile, switching from fossil fuels to heat pumps will drive up electricity demand, adding to pressure on power infrastructure.

Air-source and ground-source heat pumps need incentives to compete with oil and gas boilers



Source: Wood Mackenzie

Future energy: offshore wind

The zero-carbon technology that's attracting big capital

So much of the technology to deliver a net-carbon neutral world seems distant. Green hydrogen, carbon capture and storage, and heat pumps all need R&D and heavy subsidies before they can contribute materially. Offshore wind is more 'oven-ready' and set to take off. Soeren Lassen, head of offshore wind research, and his team identify five reasons why it's becoming central to energy companies' plans.

First, the exponential improvement and innovation in the technology, led by a competitive global OEM sector. New installations are bigger, delivering huge output gains and lower costs for each MW installed and MWh produced. The average turbine size has doubled to 8 MW in five years with more to come – the latest models on order are 14 MW.

Whereas capacity factors for onshore wind average just above 30% in many markets, offshore averages 41% with some arrays already exceeding 50%. The future is stretching into deeper water to counter nimbyism and capture greater wind speeds. Fixed installations are already reaching below 50 metres, while floating units are an emerging option for ultra-deep sites.

Second, supportive policy. European governments started incentivising offshore wind more than a decade ago as part of the drive to cut greenhouse gases. The UK, Germany and Denmark led the way, while China has also been an early adopter.

Feed-in tariffs guaranteed developers a fixed price for up to 20 years. With costs falling and the appetite to invest increasing, terms are changing towards more market-based structures – though each country has its own take on it. Competitive tender processes, shorter duration contracts and lower prices are being implemented to gradually wean offshore wind off subsidies. We reckon offshore wind could break even without subsidy inside five years in some markets.

Third, there's almost unlimited growth potential – offshore wind can work wherever the resource is close enough to market. Today, there's just 28 GW of installed capacity (equivalent to one-third of the UK's total generation capacity) and spread across a handful of countries with a North Sea coastline, and China. The US, Poland, Taiwan, Japan and South Korea are among those already committed to developing offshore wind.

OREAC, a partnership led by Orsted and Equinor, envisages capacity could be a massive 1400 GW in 2050 (the size of the US's total generation capacity), supplying 10% of the world's electricity needs. Wood Mackenzie forecasts a seven-fold increase in capacity by 2029, policy targets see an eight-fold rise to 219 GW by 2035. The industry pipeline is already above 300 GW. Government targets and the project pipeline are only going to grow.

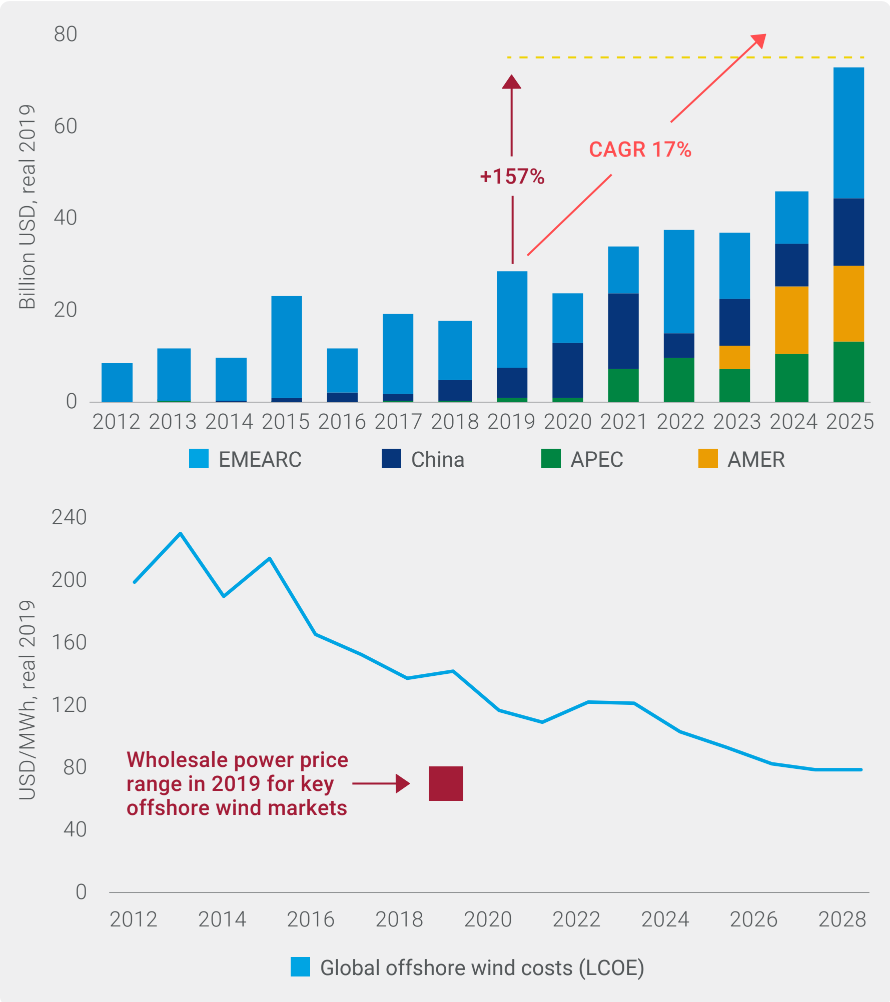
Massive investment is needed to deliver growth. We expect spend to increase from under US$20 billion in 2020 to US$60 billion in 2025 and to keep rising. There's high visibility on these numbers, with over 80% of capacity through 2025 already awarded government-sponsored support. That contrasts with upstream oil and gas where spend can snap back quickly if the oil price falls. Investment in offshore wind is just 10% of that in offshore E&P today, but conceivably could be higher by the end of the 2020s.

Fourth, the economics. Mid-single digit returns in Europe can be boosted by innovative financing. A counterpoint to modest returns is the long-life, stable cash flows the projects deliver. Our model of Equinor's giant, state-of-the-art Dogger Bank A project in the North Sea (due onstream 2024) delivers a nominal IRR of around 6% (unlevered). Project finance and proactive portfolio management can significantly enhance returns. In Dogger Bank's case the next phases, B and C, will benefit from economies of scale.

Fifth, an influx of capital. The space was niche, dominated by pioneers like Orsted and a handful of utilities. But that's changing as new players move in, including risk-averse financial investors. Big Oil will also invest in a big way. The long-life cash flow streams are more stable than volatile upstream projects, adding to the attraction of zero carbon primary production. As well as capital, Big Oil brings project execution skills; and will look for synergies by integrating renewable power with gas and trading.

Equinor, Total and Shell already have their launchpads in offshore wind. Others will follow. It's perhaps the one segment in the zero-carbon value chain that offers Big Oil the scale, organic growth opportunity and adequate returns to kick-start new energy.

Global offshore wind capex is set to triple (LHS) while costs are rapidly becoming competitive



Source: Wood Mackenzie

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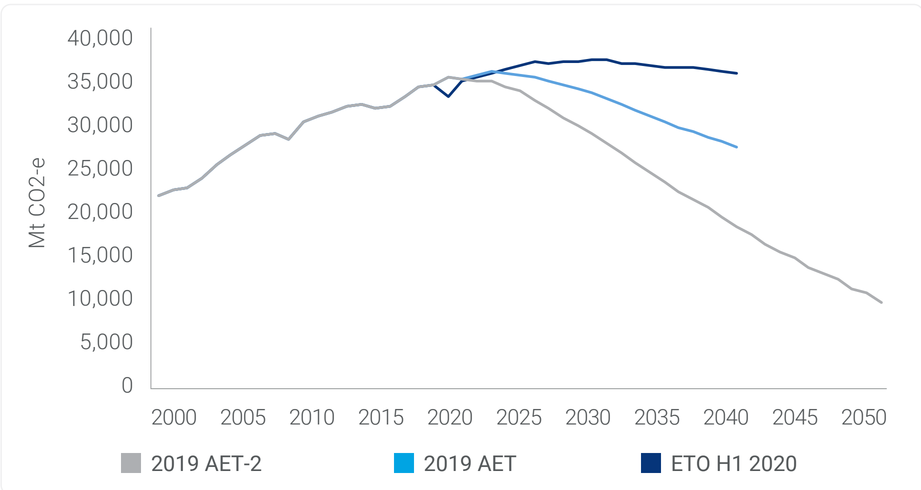

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Speak to an expert at
contactus@woodmac.com

Europe	+44 131 243 4400
Americas	+1 713 470 1600
Asia Pacific	+65 6518 0800
Email	contactus@woodmac.com
Website	www.woodmac.com

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