The EU launched its hydrogen strategy in July, placing low-carbon or clean versions — and in particular "renewable" hydrogen — front and center as an enabler to meet ambitious net-zero targets across the regions.

While the existing market for hydrogen is dominated by "gray" production, which uses fossil fuels resulting in carbon emissions, the EU strategy focuses on the development of «clean, renewable" or green hydrogen. This is produced through electrolysis of water, using carbon-free electricity from solar or wind resources. Another low-carbon option, blue hydrogen, is produced using fossil fuels from which the carbon emissions are captured and stored.

Between now and 2024, the EU aims to install at least 6 gigawatts of the electrolyzers used to create green hydrogen, to produce up to 1m tonnes. By 2030, it wants to have at least 40GW of renewable hydrogen electrolyzers, producing up to 10m tonnes of green hydrogen.

Such targets will require electrolyzer investments of €24b–€42b (US$28b–US$49b) before 2030, according to the EU strategy. An additional €220b-€340b (US$257b–US$396b) would be needed to scale up and connect 80GW–120GW of renewable energy production capacity to these electrolyzers.

While green hydrogen is the main focus of the plan, blue hydrogen will play a short- to medium-term role in the EU strategy.

Blue will "rapidly reduce emissions from existing hydrogen production and support the development of a viable market at significant scale," according to the EU strategy. And it calculates that retrofitting enough existing plants with carbon capture and storage facilities to accommodate this will cost around €11b (US$13b).

Individual European governments, including in France, the Netherlands and Germany, have followed suit in incorporating low-carbon hydrogen into their decarbonization strategies. Exploration of the role it could play in a future low-carbon economy is also taking place in other parts of the world, including Japan and Australia.

The belief that both blue and green hydrogen can play important and complementary roles in decarbonization efforts appears throughout the wave of hydrogen policy released in recent months. However, green hydrogen is beginning to attract more attention from both policymakers and investors because of its long-term sustainability.

With renewables capacity increasing globally and the cost of this power continuing to fall, green hydrogen presents a sustainable way to create and store zero-emission energy for use throughout the decarbonized economies of the future.

Making low-carbon hydrogen more cost-competitive

If green hydrogen is to fulfill this role at scale, it must become cost-competitive with blue and gray hydrogen and other conventional alternatives. According to Hydrogen Europe's *Clean Hydrogen Monitor 2020* report, the current estimated cost of producing gray hydrogen is around €1.5 per kilogram (US$1.76/kg) in Europe, depending on natural gas prices and disregarding CO2 costs. Blue hydrogen costs around €2/kg (US$2.35/kg) while green is currently produced for between €5–€6/kg (US$5.87–US$7.04/kg) on average in most EU countries.

The report adds that, for hydrogen to realize its potential in a decarbonized economy, it must be produced "on a mass scale in a sustainable way. For that to happen, however, clean [green and blue] hydrogen needs to become cost-competitive with conventional fuels. Today, neither renewable [green] hydrogen nor low-carbon [blue] hydrogen [...] are cost-competitive against fossil-based hydrogen."

Multiple studies have shown that low-carbon hydrogen costs are falling. For green, in particular, a Hydrogen Europe analysis based on average wind and solar conditions in individual European countries shows production costs could be as low as €2.9/kg (US$3.40/kg) when using photovoltaic (PV) in southern Europe and €3.5/kg (US$4.11/kg) in Germany.

But with costs still as much as two to three times higher than gray in most countries at present, reaching these lower levels will require government support. "Whether it's blue or green hydrogen, it's not yet competitive with the fuels it needs to replace – that gap needs to be filled, and policy could do that," says Allan Baker, Global Head of Power at Société Générale. "Similar to renewable energy development, that whole industry has moved from complete reliance on subsidies to a more commercial regime, and we see the same thing happening for hydrogen."

The fact that clean-hydrogen development is starting from an earlier point than renewables should also be taken into account, argues Alan Mortimer, Director of Innovation, Renewables, at energy services company Wood. As a result, he says: "In the early stages, some targeted support will be required, including grants and support for infrastructure to increase the volume of activity as early as possible. This will help the market to function and bring costs down efficiently as the industry scales up."

Decreasing renewable energy prices are a significant contributor to falling production costs for green hydrogen in particular, as are the strides taken to develop electrolyzers in recent years.

> "Similar to renewable energy development, that whole industry has moved from complete reliance on subsidies to a more commercial regime, and we see the same thing happening for hydrogen.
>
> **Allan Baker, Global Head of Power at Société Générale**

"The cost of renewable power dominates the revenue model [for green hydrogen]," says Dr Graham Cooley, Chief Executive of UK electrolyzer producer ITM Power. "The cost of the electrolyzer and its load factor are secondary, and the desire of industry to buy the hydrogen once produced is also important."

This fact has caught the attention of investors, who are becoming increasingly active right along the value chain, but particularly in the electrolyzer space.

"Electrolyzers are probably the most interesting part [of the market]," says Claes Orn, Chief Executive and Managing Partner of Geneva-based wealth management firm Orn & Cie, which manages the Thematica Future Mobility Fund. "This is the backbone of the green-hydrogen economy. It's at a very early stage, but it's very promising."

Christophe Hautin, Deputy Portfolio Manager of Allianz Global Investors' Climate Transition Fund, which invests in the European hydrogen space, adds: "As investors, we're happy to see commitments from governments and corporates in Europe to invest significant amounts of money into the sector to develop technology – electrolyzer capacity in particular. That's what is driving investor interest and the valuation of those companies in the market." However, he adds: "Subsidies are part of the solution, but certainly not enough to support the development of hydrogen to a large scale."

Indeed, scaling up production is only one side of the equation; stimulating demand for low-carbon hydrogen production will also be key to its development – and that will require support from industry and policymakers, according to investors.

Helpfully, public and private investment interest in production has also spurred a change in the industry's attitude towards integrating future low-carbon hydrogen supply. "Because the policy is there, they see incentives coming, and that has really boosted interest in [green] hydrogen recently," Cooley adds.

Governments are tightening emissions targets, making decarbonizing hard to reach, so high-emitting sectors such as transportation, domestic heating and heavy industry are an increasingly important goal.

Helping green hydrogen reach scale by developing demand.

In the transport sector, large vehicles and public transport networks are ideal candidates for a switch to hydrogen because of the high energy demands and the need for quick refueling. Long-haul trucks have the onboard space to store hydrogen tanks, while fleet vehicles – such as buses and taxis – could use centralized infrastructure for refueling.

Transportation examples such as these can also drive demand and bring down costs in a way that would enable further expansion, says Jo Bamford, owner of energy producer Ryse Hydrogen and Northern Ireland's Wrightbus.

"I have 200 buses going back to a depot every evening – that's demand," he explains. "If I've got demand, I can make production, and if I've got production, I can apply it to the rest of the economy – trucks, trains, ferries, and so on."

However, infrastructure remains "a bit of a weak link" for transportation, says Orn, of the Thematica Future Mobility Fund, although he admits there is "great will" from policymakers and industry to address this issue.

"Infrastructure is extremely important, whether it's pipelines, onsite storage or refueling stations," he says. "We see a lot of possibilities and progress on the infrastructure side. It needs investment, and the focus on the need to scale that up is now growing."

As such, this kind of high-value, relatively low-volume application is expected to be developed regionally, in line with distributed green-hydrogen production, or added to high-volume demand sources to improve economics.

In the power sector, green hydrogen could tackle intermittency issues as renewables' share of generation continues to grow. Converting power into hydrogen creates a chemical battery with more scope for long-term storage than utility battery storage.

"Whether storing wind energy that was generated at night for use the next day, or shifting solar power from the summer into the winter, that could happen at a pretty meaningful scale with hydrogen," says Alex Helpenstell, Strategy Consultant at EY-Parthenon.

While any form of clean hydrogen could be integrated into the power sector, Mitsubishi has launched a US$3b project to develop three green-hydrogen-ready power plants in New York, Virginia and Ohio. Initially capable of operating on 30% hydrogen and 70% natural gas, they could eventually reach 100% green hydrogen, according to Paul Browning, President and Chief Executive Officer of Mitsubishi Power. Once online, Mitsubishi will then build underground storage facilities connected to pipelines, to enable the plants to transition to hydrogen-only over time.

"We are trying to solve the chicken-and-egg problem where investing in hydrogen is unattractive unless there are power plants to offtake that hydrogen, but no one is going to invest without the infrastructure to supply the hydrogen," Browning explains, making a point that applies equally to any type of clean hydrogen.

"By starting out with power plants that use 30% green hydrogen we can create economies of scale, enable more renewables, and prepare for a future when we can make the infrastructure investments to fully transition from natural gas to 100% hydrogen and become part of the renewables landscape," he adds.

Pilot projects to inject hydrogen into the natural gas grid are happening in the US, Australia, Japan and throughout Europe. This could present a significant near-term demand source for low-carbon hydrogen, of which a limited amount can be blended with natural gas before existing pipeline infrastructure needs to be upgraded or end-use applications adapted.

The amount that can be blended varies by country. Germany currently allows the highest volume blend in certain circumstances, while, in France, a group of gas infrastructure operators has suggested a blend of up to 6% hydrogen could be possible right now without major changes to pipelines and end-user boilers.

In a report on its findings in this area, the group recommended a system-wide target of 10% blended hydrogen by 2030 and 20% beyond. By 2050, the report found, injected hydrogen volumes of up to 40 terawatt-hours (32% by volume) would be possible.

Reaching 100% hydrogen deployment in the gas-infrastructure sector would require large-scale conversion of end-user appliances, such as domestic boilers, and the development of safety measures for the use of hydrogen in a residential setting. However, blending even 5% would provide a significant source of demand relative to current hydrogen production, especially in the early stages of the market.

There is scope for governments to implement a feed-in tariff mechanism, as is currently used to encourage biogas injection into the UK gas grid, to help establish the existing gas market as a demand source for hydrogen.

Similarly, given the important role he believes clean hydrogen could play in terms of longer duration storage, Browning suggests a combination of state and company requirements for utilities to add more energy storage capacity, "along with incentives in the early days to help offset higher costs as we are deploying this technology and achieving scale."

He points to the UK's contracts-for-difference mechanism, and the investment and production tax-credits models used in the US for renewables development. "Those are familiar incentives that we think could equally apply to storage," Browning says.

In addition to these specific use cases, such mechanisms could also be used to incentivize investment in hydrogen production and, if applied to some of the rapidly emerging use cases around the world, to stimulate demand. Focusing efforts on developing production and demand in this way is the surest route to bringing clean hydrogen to scale.

Supporting hydrogen development through clusters

Heavy industry presents a high-volume use case for low-carbon hydrogen that could produce the necessary scale to solve the industry's "chicken and egg" dilemma, according to Jorgo Chatzimarkakis, Secretary General of Hydrogen Europe. He argues heavy industry is the low-hanging fruit that could switch to hydrogen use relatively soon.

Industrial clusters are already being explored as a way to support both production of and demand for low-carbon hydrogen simultaneously. The UK's Gigastack project, for example, is studying the feasibility of powering an industrial cluster in the Humber region in northern England. The current phase of the project would connect a 100 megawatt electrolyzer to the 1.4GW Hornsea Two wind farm, which is set to be the world's largest offshore wind development upon completion in 2022. On the demand side, the Phillips 66-owned Humber Refinery would offtake the green hydrogen produced, providing a significant demand anchor for the project. Last February, the project received £7.5m (US$9.7m) in funding from the UK Government to support this phase.

Explaining the cluster concept, EY-Parthenon's Helpenstell says: "There would be a single point of production with an anchor industrial demand, shared infrastructure for local refueling and distribution, paired with demand from ships, trains, buses, forklifts and industry operating in the area. Local authorities can support development of hydrogen by creating policies for these zones, leading to an end-to-end market in that space."

Gigastack aims to identify the regulatory, commercial and technical needs of developing clusters of hydrogen demand in energy-intensive geographic areas, such as ports that have high carbon emissions and multiple potential demand applications. Although this particular project focuses on green hydrogen, industrial clusters can also be used to support blue and green-hydrogen development, with both satisfying the same demand sources using the same infrastructure.

> “We see a lot of possibilities and progress on the infrastructure side. It needs investment, and the focus on the need to scale that up is now growing.

Claes Orn, Chief Executive and Managing Partner, Orn & Cie

Local governments can apply incentive mechanisms and production models to a specific area where a market can be created and nurtured. Infrastructure can then be built out to a nearby city for transportation, residential heating and power needs.

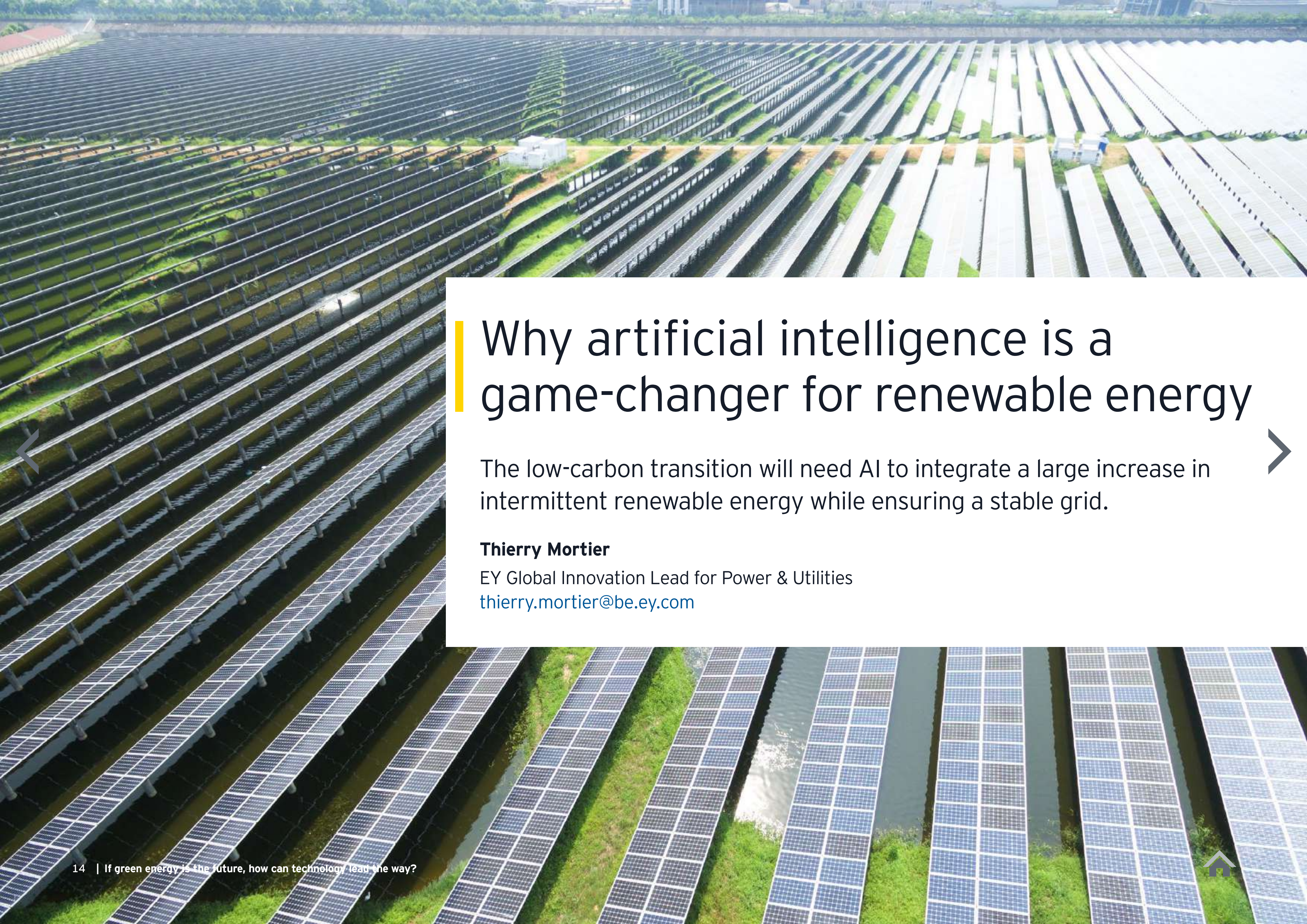
Even further down the line, hydrogen could play a role in helping entire countries to decarbonize. For those with limited domestic renewables resources, this approach could be key to reaching net-zero targets. At the moment, countries including Australia and Japan are looking into possibilities around transportation of liquefied hydrogen.

The European Hydrogen Backbone project is also exploring an almost 23,000 km pipeline network that would connect future hydrogen supply and demand centers across Europe by 2040. Three-quarters of the network would be converted from existing natural gas pipelines.

The timeline for scaling the green-hydrogen industry will depend on technical and economic factors, including the right Government support to help the industry grow.

Most importantly, large-scale development will depend on coupling renewable generation with growing electrolyzer production capacity and connecting this to a significant demand anchor, such as an industrial cluster. This will help to drive the economies of scale required to bring the hydrogen industry into line with increasingly ambitious government decarbonization targets.

Now that policymakers have recognized hydrogen’s potential in relation to decarbonization, supporting such projects will create the right signals to attract private investment to match public funds. This will enable green hydrogen to play a major role in meeting global climate action goals.



Why artificial intelligence is a game-changer for renewable energy

The low-carbon transition will need AI to integrate a large increase in intermittent renewable energy while ensuring a stable grid.

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The energy sector faces pressing challenges and needs to act with urgency. Policy commitments to a net-zero future, such as the Paris Agreement, mean the transformation to a low-carbon economy must come at pace.

Major disruption to the electricity sector is on the cards as governments ramp up renewables and transition away from fossil fuels. While renewable energy looks set to flourish amid this backdrop, its intermittent nature means solutions will need to be found to keep grids stable. Additionally, the industry is changing from a market based on commodity pricing to a market based on technology solutions in order to integrate renewable energy. As the energy industry continues to utilize more variable generation sources, accurate forecasts of power generation and net load are becoming essential to maintain system reliability, minimize carbon emissions and maximize renewable energy resources.

As we move into the Fourth Industrial Revolution, grid operators, developers and consumers are harnessing artificial intelligence (AI), paving a path for a smooth transition to a greater use of renewables. AI's ability to provide better prediction capabilities is enabling improved demand forecasting and asset management, while its automation capability is driving operational excellence – leading, in turn, to competitive advantage and cost-savings for stakeholders.

Supported by other emerging technologies, such as the internet of things (IoT), sensors, big data and distributed ledger technology, AI has the ability to unlock the vast potential of renewables. Failure to embrace it would leave the renewable energy sector falling behind.

AI is far superior to humans when it comes to carrying out complex tasks at speed. Given that an energy grid is one of the most complex machines ever built and requires split-second decisions to be made in real time, AI algorithms are a perfect fit.

How AI is transforming renewable energy

As an increasing amount of megawatts feeds into the grid from variable renewable energy sources, predicting capacity levels has become paramount to secure a stable and efficient grid. This is due to the fact that with renewables taking up a greater share of the grid, there is a loss of baseload generation from sources such as coal, which provide grid inertia via the presence of heavy rotating equipment such as steam and gas turbines. Without grid inertia, power networks will be unstable and susceptible to blackouts. Now, with the application of sensor technology, solar and wind generation can provide an enormous amount of real-time data, allowing AI to predict capacity levels.

Before harnessing AI, most forecasting techniques relied on individual weather models that offered a narrow view of the variables that affect the availability of renewable energy. Now, AI programs have been developed – such as IBM's program for the US Department of Energy's SunShot Initiative – which combine self-learning weather models, datasets of historical weather data, real-time measurement from local weather stations, sensor networks and cloud information derived from satellite imagery and sky cameras.

The result has been a 30% improvement in accuracy in solar forecasting, leading to gains on multiple fronts. "We found that improved solar forecasts decreased operational electricity generation costs, decreased start and shutdown costs of conventional generators, and reduced solar power curtailment," says Hendrik Hamann, IBM Distinguished Researcher and Chief Scientist for Geoinformatics.

Forecasts of the base variables – wind speed and global horizontal irradiance, as well as the resulting power output – allows for a view on a range of time horizons, from minutes and hours ahead (for maintaining grid stability and dispatching resources) to day-ahead (optimizing plant availability), to several days ahead (scheduling maintenance).

With increasingly larger data sets becoming available, predictions can now go far beyond the weather to train algorithms to predict more remarkable outcomes. For instance, how much additional power is used during a festive holiday, a large-scale international event, or how much altitude impacts a community's energy use.

For generators and energy traders, more accurate forecasting of variable renewable energy at shorter timescales allows them to better forecast their output and to bid in the wholesale and balancing markets – and, importantly, to do so while avoiding penalties.

"The earlier and more accurately you can predict, the more efficient it is for energy traders to rebalance their position. I see AI providing a way of dealing with lots more sites and using more granular and diverse data than historic forecast methods," says Alex Howard, Head of Strategy at Origami. "Ultimately, that means making a better financial return."

For generators and energy traders, more accurate forecasting of variable renewable energy at shorter timescales allows them to better forecast their output and to bid in the wholesale and balancing markets – and, importantly, to do so while avoiding penalties.

Meanwhile, for grid operators, AI algorithms with vast amounts of weather data can ensure optimal use of power grids by adapting operations to the weather conditions at any time. More accurate short-term forecasting can result in better unit commitment and increased dispatch efficiency, thereby improving reliability and reducing operating reserves needed.

"Now, with AI, we can predict more accurately what renewables are likely to do, so we can control other power plants more accurately, like coal plants that take many hours to ramp up," says James Kelloway, Energy Intelligence Manager at National Grid ESO.

In turn, cost-savings can be passed along. He adds: "What we want to avoid is turning the renewables off. From a price-tag perspective and the way the system is configured, renewables are not only greener, they are usually cheaper."

Through a grid-stability lens, with AI ensuring that the power grid operates at optimal load, grid operators can optimize the energy consumption of consumers. But it is not only transmission system operators that can utilize AI; its application goes beyond central planning and can play a bigger role on the edge of the grid with machine-to-machine communication. In an ideal situation, electricity generated within a neighborhood grid or solar PV system can be used to improve reliability and combat grid congestion – which is associated with complex, decentralized systems with bi-directional electricity flow.

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We found that improved solar forecasts decreased operational electricity generation costs, decreased start and shutdown costs of conventional generators, and reduced solar power curtailment.

Hendrik Hamann, Chief Scientist for Geoinformatics, IBM

Equally important is accurate demand forecasting – and here, too, AI has a key role to play given its ability to optimize economic load dispatch and improve demand-side management. Increasing installation of smart meters has enabled demand data to be sent to utility providers. AI algorithms can absorb the data, which can be sent as frequently as hourly, and predict network load and consumption habits accurately.

For consumers, utility bills can be reduced, with AI systems predicting a building's thermal energy demand to produce heating and cooling at the correct times through optimization of home solar and battery systems. Efficiency gains are combined with load shifting to times when electricity is cheapest, with renewable electricity available in the system.

"We can now predict when demand spikes will occur and discharge energy to keep customers' grid-supplied electricity below a certain set point, and, consequently, help customers control energy costs without interrupting operations or requiring any involvement on their part," says Josh Lehman, Senior Director of Product Management at US energy storage firm Stem. He adds that the company's AI-driven software has improved customer savings by approximately 5% year-on-year.

In the all-important flexibility jigsaw, the ability to understand consumers' habits and actions creates greater flexibility in a smart grid because AI algorithms can make predictions about a building's energy use 24 hours in advance, based on its experiences in the past.

Battery storage also has an important role to play in providing demand flexibility, with AI again playing a pivotal part. As storage batteries can be activated quickly and used to manage excessive peaks – as well as minimize the back-up energy needed from diesel generators, coalfired power plants or other gas-fired "peaker" plants that are utilized at peak demand – AI can predict and make energy storage management decisions by considering forecast demand, renewable energy generation, prices and network congestion, among other variables.

Battery owners can deploy their storage pack according to the compensation for the services provided by the battery. Stem has developed AI algorithms to map out energy usage and allow customers to track fluctuations in energy rate to use storage more efficiently.

In the all-important flexibility jigsaw, the ability to understand consumers' habits and actions creates greater flexibility in a smart grid because AI algorithms can make predictions about a building's energy use 24 hours in advance, based on its experiences in the past.

Similarly, US-based software-as-a-service platform provider AMS uses AI in versatile battery storage systems to optimize opportunities to purchase electricity from the grid when prices are low, and then sell back to the market when prices are high. Another case is Australia's Hornsdale battery, with 150MW, which operates an autobidder AI algorithm, developed by Tesla, that has allowed the project to capture revenue streams about five times higher than an energy trader, according to AMS.

For electricity providers, AI can also assist with operations and maintenance of asset management. AI algorithms can automatically detect disturbances in real time of mechanical failure, thereby improving reliability and efficiency in the power system. By using data from sensors, algorithms can learn to distinguish and precisely categorize normal operating data from defined system malfunctions.

"Unexpected disruptions across the industry can cost 3%–8% of capacity and US$10b annual lost-production cost," says Brian Case, Chief Digital Officer at GE Renewable Energy. Its Predix software is embedded with AI-based algorithms that can interpret industrial data to make predictions on machine health and recommend actions to improve efficiency for assets such as wind farms.

AI's ability to root out system malfunctions immediately can also prevent a chain reaction. For instance, if one power plant should fail, an abrupt spike can be expected in the load placed on other power plants. This, in turn, slows down the generators, and the frequency decreases. If the frequency sinks below a threshold value, the operator may be required to cut off sections of the grid to maintain system stability. The ability of AI algorithms to make split-second decisions allows for appropriate, fully automated countermeasures to be taken.

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Unexpected disruptions across the industry can cost 3%–8% of capacity and US$10b annual lost-production cost.

Brian Case, Chief Digital Officer at GE Renewable Energy

Finally, at a regulatory level, AI unlocks legislation to be created more effectively. It also provides insight into human motivations tied to renewable energy adoption and how consumer behaviors could possibly be changed to optimize the energy system.

The challenges of applying AI across the sector

AI's potential to be a game-changer for the renewable energy sector is undeniable, but that does not mean its greater application across the sector is devoid of challenges.

In today's digital age, concerns have emerged that relying on AI too much could leave energy networks vulnerable to cyber attacks. A wake-up call came in 2015, when hackers took 30 substations offline in Ukraine, leaving 230,000 people in the dark for six hours. A second, much smaller attack occurred on a transmission station a year later, in Kiev. It is believed the 2015 attack required months of planning and a team of dozens working in coordination and was largely due to the fact employees fell for a phishing campaign.

Another type of cyber attack on power grids that has been deployed more recently involves exploiting vulnerabilities in firewall firmware. In 2019, the North American Electric Reliability Corporation revealed that the first attack on a US grid network occurred with an undisclosed utility suffering communication outages between its control center and generation sites. The disruption was a result of an outside party rebooting the company's firewalls. Each communication failure lasted less than five minutes, but the entire attack went on for about 10 hours.

However, the likelihood of another successful large-scale attack appears minimal. Operational technology (OT) systems are isolated from information technology (IT) systems, with no network connections between the two, and are, therefore, much more difficult to infiltrate. In addition, OT systems are more customized and esoteric, so they are far less familiar to would-be hackers.

If hackers did get into operations networks, they would need to learn the equipment and setups. Moreover, whatever equipment setup a utility may have, its physical processes can require real expertise to manipulate, as well as months' more effort and resources. Ultimately, experts believe the vast majority of grid-penetration incidents will amount to little more than spear phishing.

From a performance perspective, data bias, audit and ongoing verification of algorithms are issues that AI systems must consider when developing algorithms. Machine learning is ultra-sensitive to poor data, with the adage "garbage in, garbage out" holding true here. It is critical that data is taken and made machine readable, so that it is quality in, quality out. For trusted AI, frequent verification of data is a necessity to ensure algorithms remain valid over time and that as the machines learn they do not deviate from the original algorithms.

Concerns have emerged that relying on AI too much could leave energy networks vulnerable to cyber attacks. However, operational technology systems are isolated from IT systems, with no network connections between the two, and are, therefore, much more difficult to infiltrate.

That is not always as easy as it sounds, however. "AI may have some limitations in areas that don't have the historical data available to find the intelligence, because it has never occurred or existed before," warns Hamann, at IBM. "You can, though, overcome these challenges by using different, more, and more selective data sources, as well as different techniques."

From a technology perspective, reliance on cellular technologies would limit AI's potential in rural and other under-served areas in many emerging markets, particularly low-income countries. Smart meters rely on constant data communication, so a lack of reliable connectivity is a substantial impediment in areas where cellular network coverage is sparse or limited.

As with all new technology, AI is likely to face initial mistrust from consumers. Building owners and occupants are likely to be skeptical that the technology can deliver reductions in either energy consumption or cost without compromising energy services and comfort. Robust education and marketing programs will be needed to convince customers to trust the technology.

Regulatory barriers also exist, including the fact that energy markets' rules must permit the trading of flexible demand at a scale that allows commercial buildings to participate in the market. In some energy markets, for instance, the minimum allowable bids for participating are higher than the size of flexible loads likely to be offered by commercial buildings. In addition, some energy markets require access fees for participation, which might pose a barrier to entry for small-scale participants.