Unlocking the Green Hydrogen Revolution

By driving down the cost of green hydrogen by 2030, wind can accelerate a carbon-free future and halt climate change

SIEMENS Gamesa
RENEWABLE ENERGY

Foreword

Why now is the time for green hydrogen

The climate emergency is real. 2020 was the joint warmest year on record[1]. The concentration of carbon dioxide in the atmosphere continues to grow. Sea levels are rising[2] at the same time as the world's oceans continue to heat up[3].

The problem facing the world is that we no longer have the luxury of waiting and seeing. Co-ordinated and accelerated action is needed.

During 2020, many countries and regions pledged for carbon neutrality by mid-century[4]. The only way to reach the targets set forth in the Paris Agreement is by turning pledges into action, now. Governments, businesses and institutions will meet in Glasgow this November for the COP26 Conference to discuss progress made so far and how best to achieve the next phase of carbon reduction.

In order to contain the climate emergency, renewable energy production needs to be scaled up even further in order to meet the energy demands of an expanding global population. Last year, for the first time, renewables generated more electricity than fossil fuels across the EU[5], spurred on by new solar and wind power projects which will establish renewables as the primary source for electricity generation.

Where possible, electrification based on renewables is the most cost-effective and most efficient option for decarbonization. However, there are some sectors that have power needs which cannot be met by electrification. Industry and transportation make up 35 % of global greenhouse gas emissions (GHG) which is where we find the hard-to-electrify end-uses. Iron and steel, cement, chemical production, along with heavy transportation such as shipping, aviation and heavy-duty trucks are all significant CO2 emitting activities which are hard, or completely impossible, to electrify. Transitioning these sectors to zero carbon needs fresh thinking, because without addressing these hard-to-electrify sectors, the climate will continue to warm.

Green hydrogen – hydrogen which is produced by electrolysis powered by a renewable energy source – is a key building block for reducing the emissions from these high CO2 emitting industries.

This paper offers not only an overview of what needs to happen to make green hydrogen viable but also outlines how Siemens Gamesa's expertise in generating energy from renewable sources will allow green hydrogen to be produced globally, at scale, cost effectively.

Whenever there is an emergency, timing is critical. The urgency of the situation should be framed as an incentive rather than a threat. The momentum built up by renewables needs to be harnessed to catapult green hydrogen into the mainstream and ensure that the ambitious targets set by governments around the world are met on time, if not sooner.

Andreas Nauen
CEO, Siemens Gamesa Renewable Energy

“Green hydrogen offers developing countries the possibility of producing a local clean fuel that can be used to decarbonize hard-to-electrify activities in transport, industry and buildings, while enhancing energy security. This report from Siemens Gamesa rightly underscores the important role that renewable energy production in general, and wind power in particular, will have in scaling up green hydrogen in time to meet the 2050 net-zero goals.”

Fernando de Sisternes, Green Hydrogen Lead at ESMAP, The World Bank

Unlocking the green hydrogen revolution

Executive Summary

By driving down the cost of green hydrogen by 2030, wind can accelerate a carbon-free future and halt climate change

Why price parity matters

Without the production of green hydrogen on an industrial scale, the world will not achieve carbon neutrality by 2050 and the earth's temperature will continue to rise. Its importance is underlined by the fact it features in all eight of the European Commission's net zero emissions scenarios for 2050.

Low-cost production is critical to decarbonize hard-to-electrify sectors such as steel and chemical industries, maritime shipping, long-haul road transport and aviation. This paper sets out an ambitious plan to deliver cost-competitive green hydrogen by 2030. And while the scale of the challenge is significant, if industry, governments and investors work together it is achievable.

Key to unlocking the green hydrogen market is price parity or fossil parity with grey hydrogen, hydrogen produced by fossil fuels. Fossil parity is where the price of green hydrogen equals that of grey hydrogen, and Siemens Gamesa believes that this is achievable from onshore wind generation by 2030 and from offshore wind generation by 2035[6].

While it took three decades for wind and solar to reach grid parity with fossil fuels, green hydrogen needs to be cost-competitive with fossil-fuel generated hydrogen in one decade. There is no time to waste if we are to deliver on this timeline.

Why do we need green hydrogen?

In 2019, the global hydrogen demand was 75 million tons[7], accounting for 6 % of global natural gas consumption and 2 % of the coal consumption. Demand for hydrogen in hard-to-electrify sectors is expected to increase by 7 % per year until 2050.

By eliminating greenhouse gas emissions from today's hydrogen production by using renewable energy instead of fossil fuels, we will deliver a cleaner, more sustainable future. The unlimited supply of renewable energy and capabilities having proven by the renewables value chain mean that the volume of green hydrogen production is almost unlimited.

Overcoming the challenges to scaling green hydrogen

There needs to be a collaborative and joined-up approach between the private sector, governments and public authorities, and investors to overcome the triple challenge of scaling up production which includes:

1. Coordinating efforts to increase installed electrolyzer capacity, which in Europe alone needs to scale up from less than 1 GW today to 40 GW by 2030; and 500 GW by 2050 based on projected investment in production capacities by mid-century.[8]
2. Developing solutions to effectively store, distribute and transport hydrogen, whether in gaseous or liquid form.
3. Putting in place policy frameworks that support and encourage ongoing private sector innovation in green hydrogen while securing future market demand.

Delivering low-cost green hydrogen by 2030

We can't underestimate the challenge of producing green hydrogen at the scale needed to deliver on the 2050 net zero targets. There are four key requirements to deliver low-cost green hydrogen at scale within the next decade:

1. **Increase the capacity of renewables:** The green hydrogen revolution can only happen if renewable energy deployment is accelerated. By 2050, it's expected that demand for hydrogen will reach 500 million tonnes[9]. For the majority of this to be met by green hydrogen, it will require between 3,000 and 6,000 GW of new installed renewable capacity, up from 2,800 GW today. Governments need to accelerate their plans, and industry needs to scale its output, production and logistics. As governments around the world look to green the recovery post-pandemic, there is opportunity to do this while benefiting from the wider socio-economic benefits of renewable deployment.

2. **Create a cost-effective demand-side market for green hydrogen:** Increasing demand will get a green hydrogen economy started, create market size and help lower costs of equipment, infrastructure, operating costs and also lower the overall financing cost. Currently, the main operating cost for green hydrogen production is powering the electrolyzers, so a decrease in energy cost lowers the cost of the hydrogen and increases demand. Similarly, estimates suggest that the cost of electrolyzers will come down from c.1000 €/kW today to less than 500 €/kW in the coming decade[10].

3. **Develop a supply chain:** There is not one provider in the market which can take ownership of the entire hydrogen production and distribution process – without working together green hydrogen will remain fragmented, unfulfilled, costly and outside of the energy mainstream. Renewable energy companies, electrolyzer manufacturers, hydrogen network providers, water treatment specialists, etc. will all have to collaborate to build a supply chain that is resilient and able to scale quickly as demand requires.

4. **Support the right infrastructure:** Logistics, storage and distribution need to be factored into the end-to-end green hydrogen market. There needs to be investment in hydrogen grid networks, whether new or retrofitted, that will help to embed green hydrogen as mainstream energy source. While plans are taking place in Europe, with initiatives such as the European Hydrogen Backbone Plan, these grids need to be considered across all regions around the world as infrastructure is vital to unlocking the potential of hydrogen.

Ambition and action is key to unlocking the potential of green hydrogen

Green hydrogen offers immense potential as we seek to decarbonize the global economy and address the climate emergency. Innovating in wind-to-hydrogen solutions, both onshore and offshore, further unlocks the potential of wind energy, hastening the journey towards net zero. The scale of the challenge is clear but the opportunity in terms of delivering a carbon-neutral future is clearer still. Industry, governments and investors need to work together to build an environment where innovation is encouraged, where market demand is fostered and where collaboration between different players in the supply chain is incentivized[11].

1 Why green hydrogen?

Key takeaways

Many sectors of the global economy are hard to electrify, including steel and chemical industries, maritime shipping, long-haul road transport and aviation, and therefore cost-competitive green hydrogen is vital to helping them to decarbonize.

In 2019, the global hydrogen demand was 75 million tons[12], accounting for 6 % of global natural gas consumption and 2 % of the coal consumption. Demand for hydrogen is expected to increase by 7 % per year until 2050 and unless this is generated using renewable energy, the world is unlikely to meet its net zero targets.

Wind can be harnessed to produce hydrogen, but this can only be achieved at scale through the acceleration of renewable energy projects, and putting in place the frameworks to encourage collaboration, partnership and innovation needed to fuel the green hydrogen revolution.

H_2

Green hydrogen at scale is key to decarbonizing the global economy

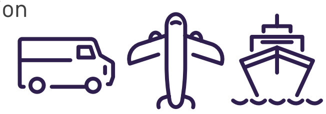
There is nothing new about hydrogen – it was with us 13 billion years ago, at the time of the Big Bang[13]. Similarly, there is nothing new about hydrogen as an industry feedstock in the post-industrial world. What is new is the realization that green hydrogen can be produced at scale using renewable energy, supporting the transition to a decarbonized global economy.

Hydrogen is today used primarily in refining processes or to make ammonia for the fertilizer industry. As things stand, 98 % of today's hydrogen is produced using fossil fuels, mainly by reforming natural gas and through coal gasification[14]. But emissions can be eradicated if renewable energy is used to produce the hydrogen.

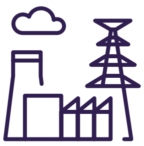
In 2019, the global hydrogen demand was 75 million tons[15]. Producing this accounts for 6 % of global natural gas consumption and 2 % of the coal consumption. If these emissions alone came from one country, it would be the second largest emitter in Europe and close to the highest emitter, Germany.

Fuel for:

Transport
Trucks Aviation
Shipping



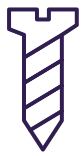
Power
Electricity
Peaking Plants



Feedstock for:

Chemicals
Fertilizers
Fuel refining
Plastics

Products
Metallurgy
Food
Steel
Glass



Source: BNEF

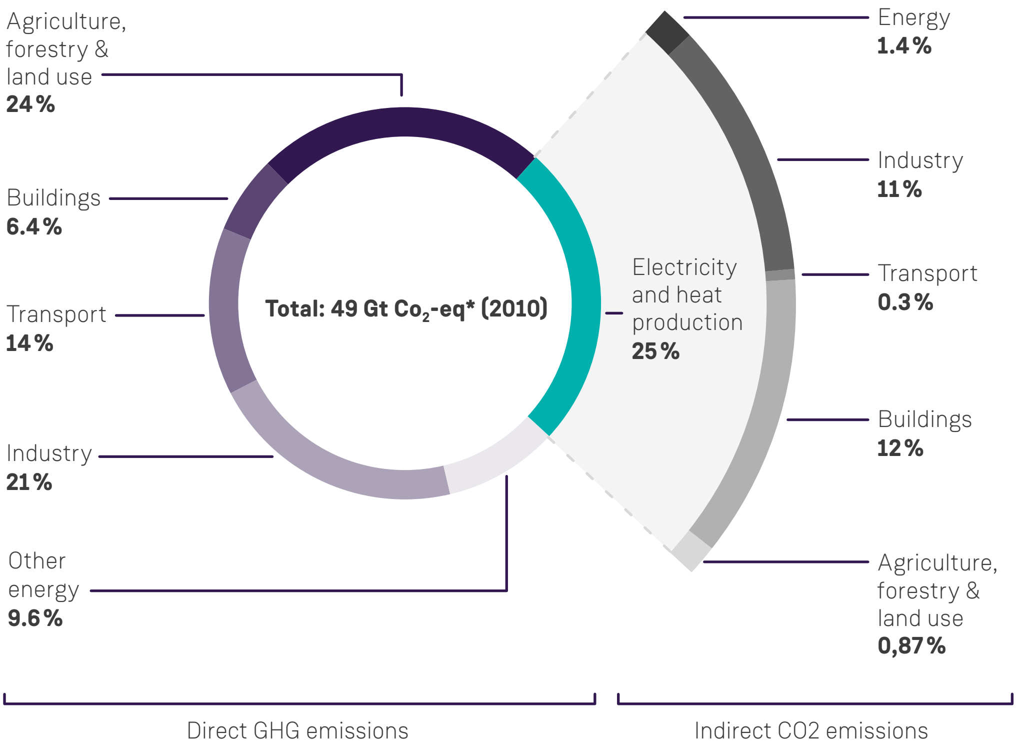
"I strongly believe that the next step of the global energy transition will be based on the hydrogen economy – transforming "green electrons" to "green molecules" via water electrolysis. These chemicals can be transformed, stored, transported and used in various sectors. This sector coupling approach allows to decarbonize applications whose electrification will come to its limits. This is the case in industry, mobility or energy sectors. So, sectors that formerly rather developed independently could be linked in the future via green hydrogen. That's why we see hydrogen as a key enabler for sector coupling. Additionally, in many regions hydrogen is a viable option to store and transport excess electricity from wind or solar over longer periods and in huge amounts – making renewable energy from wind- or sun-rich regions available for energy-hungry regions."

Prof. Dr. Armin Schnettler
EVP New Energy Business, Siemens Energy

The hydrogen roadmap needs to address all use cases: replacing fossil-based hydrogen with green hydrogen in existing energy intensive applications; preparing for green hydrogen and hydrogen-based fuels to ease the transition away from diesel, petrol, gasoline, bunker fuel and kerosene; and working with partners to innovate on future use cases.

Eliminating the greenhouse gas emissions from today's hydrogen production by using renewable energy instead of fossil fuels will push the transition to a cleaner, more sustainable future.

GHG emissions by economic sectors



Source: IPCC, Synthesis report, 2014, p. 47

*Gt Co_2-eq = Gigatonnes of equivalent carbon dioxide

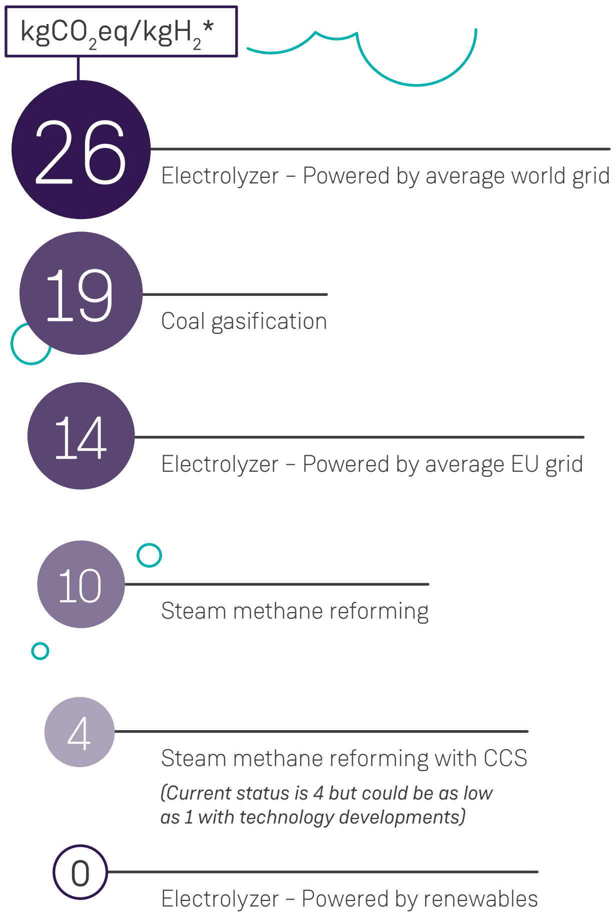
Producing green hydrogen

Hydrogen is one of the most abundant elements in the universe. But on Earth, there is not enough naturally occurring hydrogen available. It needs to be produced by extracting it from other compounds.

Green hydrogen is generated by splitting water into hydrogen and oxygen. The oxygen is released back into the atmosphere, while the hydrogen can be stored in a gaseous or liquid state. This process is known as water electrolysis and the hardware used to split the water is an electrolyzer. If the electricity used to power the electrolyzer comes solely from renewable energy sources, there are no greenhouse gas emissions associated with the hydrogen production. In this case, the hydrogen is referred to as green hydrogen.

The potential volume of green hydrogen production is almost unlimited because there is an unlimited global supply of renewable energy available to power the electrolyzers.

GHG emissions from hydrogen production



IEA: The future of Hydrogen, 2019, p. 38; p. 53.
European Commission: A Hydrogen strategy for a climate-neutral Europe, 2020, pp. 3–4.

*$kgCO_2eq/kgH_2$ is a unit that measures how much CO_2eq is released into the atmosphere to produce 1 kg of hydrogen. CO_2eq accounts for all greenhouse gases (methane, nitrous oxide, etc.) and transfers it to the global warming effect of the equivalent amount of CO_2.

Transforming challenges into opportunities by creating the right frameworks for investment

Hydrogen's potential to support the transition to a decarbonized global economy is not without its challenges, most of which can be addressed through setting the right framework conditions and enhancing collaboration, partnerships and innovation.

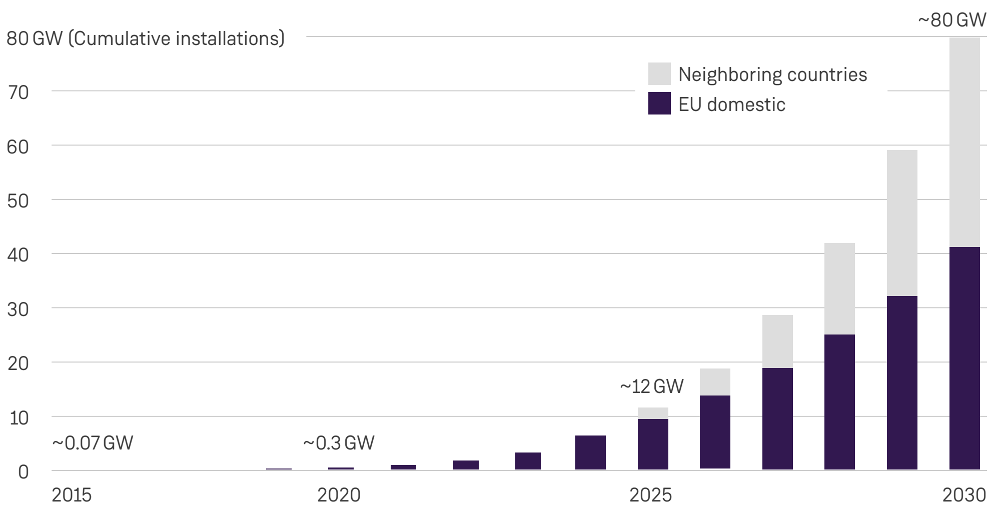
As things stand, the biggest headwind for green hydrogen at scale is how much hydrogen can currently be produced by the renewable energy powered electrolyzers. The EU's hydrogen strategy released in July 2020 targets 40 GW of electrolyzer capacity installed in Europe by 2030, a massive increase on current levels of less than 1 GW[16], and 500 GW by 2050 based on projected investment in production capacities by mid-century.

Challenges also exist around storage, distribution and transportation. Hydrogen has a low energy density by volume. It requires high pressure, possibly combined with low temperatures, to be transported or stored in either gaseous or liquid form. The industry needs to find ways to accommodate the physical properties of hydrogen, including its volatility.

Innovation and expansion of green hydrogen is not dependent on a market in the short-term, but visibility into future pricing will be needed as the scale and ambition of projects increases. Renewables have grown from a small supporting actor in the 1990's electricity sector to having a starring role in today's market and that of the future. This has been based on support from governments in the early years, target setting and forward-looking planning. The industry has played its part with continuous investment in innovation and lowered costs based on both leapfrogging developments and economies of scale.

However, to steer the world to a zero-carbon future, the uptake of green hydrogen must be achieved at triple the speed of renewables. Through dedicated efforts wind and solar achieved grid parity with fossil fuels in three decades, green hydrogen must now get on par with fossil fuel hydrogen in one decade.

The EU hydrogen strategy sets target of 2 x 40 GW electrolyzer installed capacity by 2030



* 40 GW in Europe and 40 GW in Europe's neighborhood with export to the EU.
Source: European Commission: A Hydrogen strategy for a climate-neutral Europe, 2020, p. 2–3.

Planning for green hydrogen requires action today

In order to mitigate the most extreme consequences of climate change, the increase in temperature needs to be well below 2 degrees Celsius, preferably limited to 1.5 degrees Celsius, compared to pre-industrial levels[17]. Achieving this requires scaling up renewables to support the decarbonization of the entire energy sector.

In the past couple of decades, advances in technology and continued innovation have made the limitless natural energy resources from sun and wind widely available. Costs have come down, with BNEF's New Energy Outlook 2020[18] confirming that "more than the two thirds of the global population lives in countries where solar and wind are the cheapest sources of new bulk generation."

Solar, onshore and offshore wind are now leading the charge towards a sustainable global energy supply. Over the next few years, green hydrogen will start to play a similar important role and has the potential to scale up, helping reduce emissions from existing fossil fuel-based processes while introducing new and innovative use cases.

The potential for green hydrogen to help decarbonize the global economy is now recognized. The reason being competitiveness and performance of renewable energy, supported by the fact that wind and solar are widely available, in almost unlimited volumes, at reasonable cost.

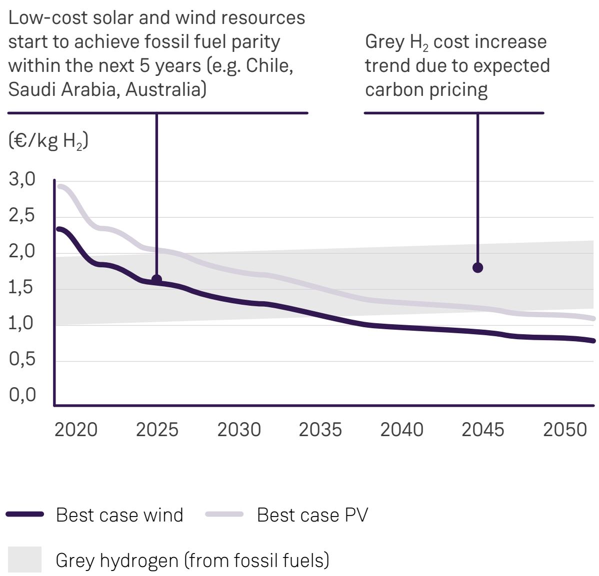
At the same time, the use cases for green hydrogen are becoming more ambitious in terms of production volumes, creating the significant economies of scale needed to drive interest, investment and returns.

The energy needed to power the electrolyzers is the biggest operating cost when producing green hydrogen today. But as the cost of renewable energy comes down in price, so does the cost of the hydrogen produced. As renewable energy capacity factors increase, electrolyzer output is increasing, creating a win-win scenario where producing more will cost less.

Existing onshore wind farms can be combined with electrolyzer facilities not only to kickstart green hydrogen production immediately, but also to support the scale-up of the electrolyzer supply chain. Hydrogen as a new energy carrier vector can provide an alternative pathway that not only helps to integrate renewable power generation, but also enables the decarbonization of the transportation and natural-gas sectors.

Future cost of green hydrogen

Levelized cost of hydrogen (LCOH)

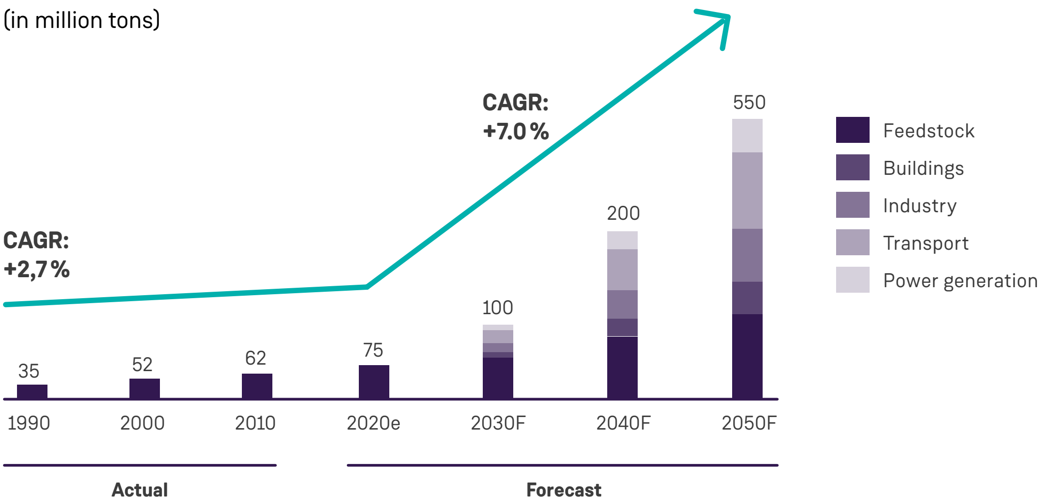


Source: Internal Siemens Gamesa graph

In the mid to long term, in the regions with strong offshore wind resources due to higher offshore wind turbine capacity factors, green hydrogen production at sea will be a highly effective way to generate the volumes at the scale needed.

To meet the current and anticipated global demand, which is predicted to grow by 7 % per annum through 2050, the availability of green hydrogen needs scaling up.

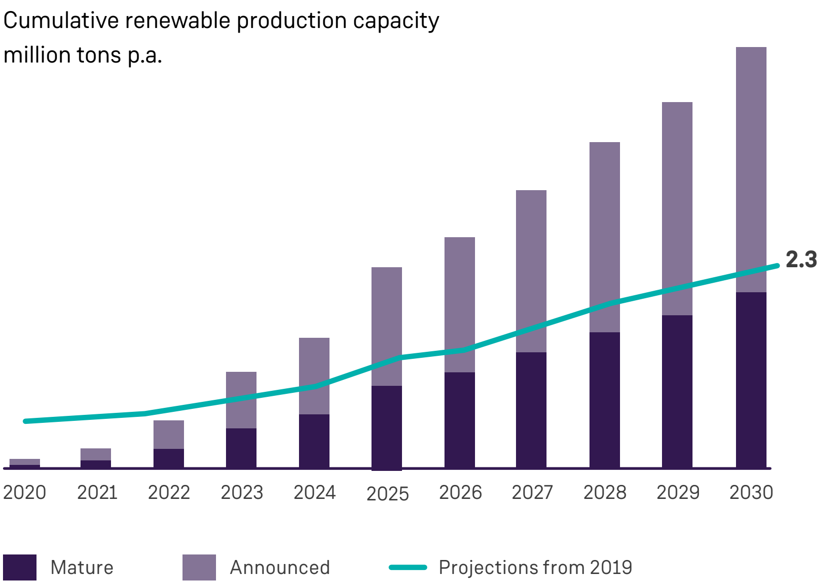
Global annual demand for hydrogen



Source: Internal Siemens Gamesa graph

A holistic approach to a global hydrogen market and its value chain is necessary to fully deliver on the promise of green hydrogen, and to ensure that there is a commercial pathway in place to justify the investments needed.

Announced clean hydrogen capacity though 2030



Source: Hydrogen Council: Hydrogen insights, 2021, p. 18.

2 Transition in action

As one of the pioneering companies in the sector, Siemens Gamesa has been at the forefront of wind energy for the past thirty years. It is proud to have been involved in the development of new technologies, helping on- and offshore wind achieve price and performance parity with fossil fuels, while building a resilient economic sector.

But electricity grid parity is only the first step – in time wind, together with solar, will be the cheapest and most reliable form of energy on the market everywhere, outperforming legacy fossil fuels on every metric, capable of generating 100 % of the world's energy needs.

The transition to zero carbon needs to start happening now, and Siemens Gamesa is already active across the ecosystem with concrete projects, confirmed investments and long-term commitments.

Key takeaways

By integrating a wind turbine, a battery and an electrolyzer, there is potential to enable the production of industrial-scale volumes of green hydrogen in the near term from existing wind projects – this is currently being explored at the Brande Hydrogen site in Denmark.

Siemens Gamesa and Siemens Energy have announced development projects leading to a fully integrated offshore wind-to-hydrogen solution to enable green hydrogen production at scale by fully integrating an electrolyzer into a dedicated platform at the base of an offshore wind turbine.

Cost-effective production of industrial volumes of green hydrogen can be driven by three factors: operating in 'island mode' means turbines are independent of grid connection so output can be maximized; combining the electrolyzer with the turbine in one integrated system increases hydrogen per kWh; standard modular design means that components are not specific to each project, resulting in lower potential supply chain impacts.

Brande Hydrogen test site as use case for large-scale production

Siemens Gamesa's first foray into hydrogen is the pilot test site known as Brande Hydrogen, which couples an existing onshore Siemens Gamesa SWT 3.0-113 DD wind turbine with an electrolyzer stack.

The setup enables a number of tests and experiments, with some successes already achieved. Brande Hydrogen shows that green hydrogen can be produced without using any energy from the grid, known as "island mode". The green hydrogen fuel produced is then distributed by Everfuel, a Danish company, to power Copenhagen's fuel cell taxi fleet.

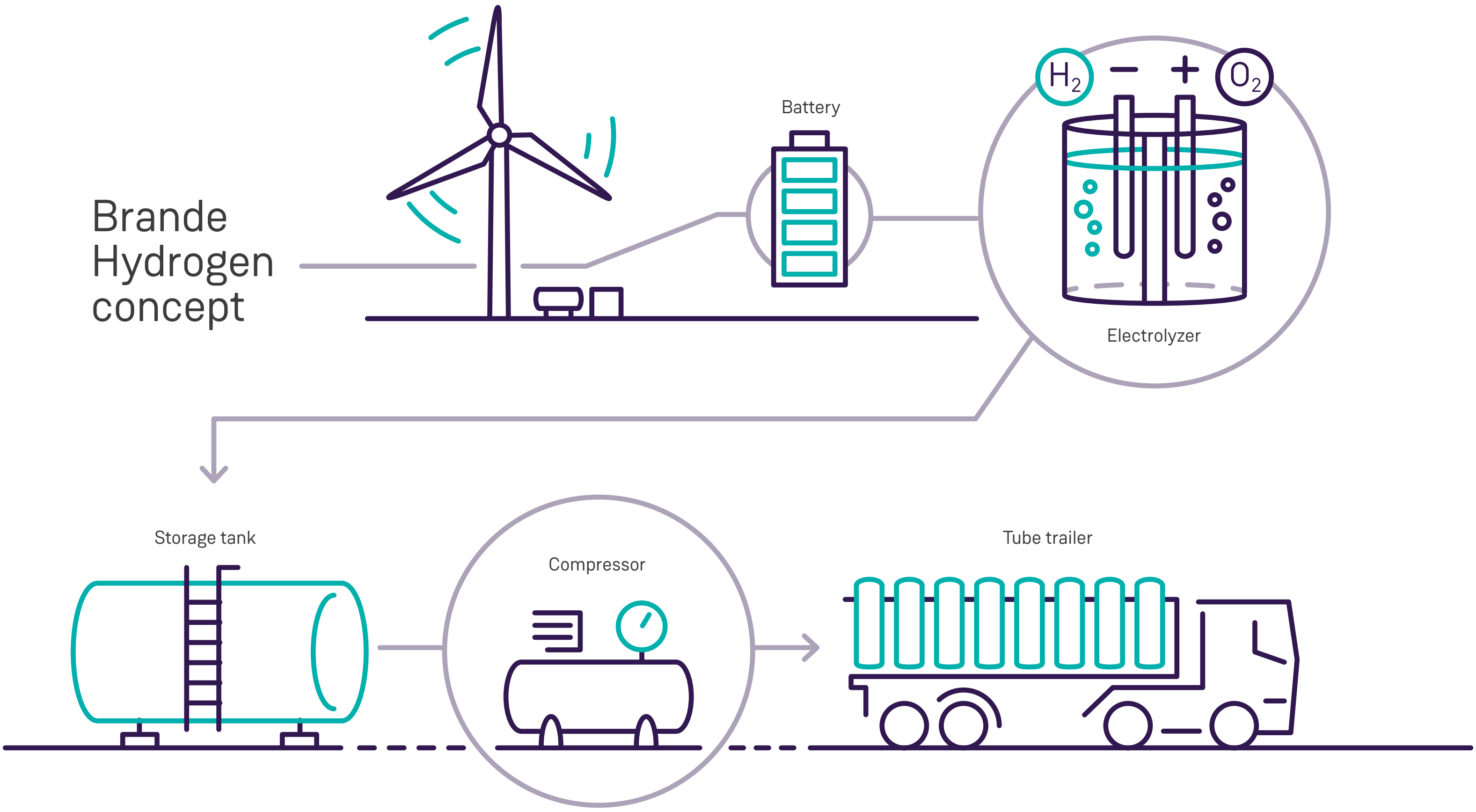
Siemens Gamesa is also using the Brande Hydrogen site to explore whether integrating new battery technology as an upgrade to the co-located turbine and electrolyzer can contribute to grid stability and help address issues around the variability of wind.

This combination also has the potential to expand the output of existing wind projects. Batteries can store energy in a way that allows electrolyzers to run for longer and produce more green hydrogen.

If there is a grid connection, the batteries can distribute the renewable energy to the grid rather than the electrolyzer when conditions allow, easing bottlenecks and providing flexibility.

The battery, turbine and electrolyzer setup has the potential to enable the production of industrial-scale volumes of green hydrogen in the near term.

Innovations and learnings from the Brande Hydrogen test site will be shared with partners to build use cases for larger-scale green hydrogen production.



Brande Hydrogen test site near Brande, Denmark

“There are lots of colors of hydrogen – green, blue, turquoise, yellow and more have been proposed. But only one form of hydrogen is truly sustainable and fully carbon free: green hydrogen, based on 100 % renewable electricity. Thus for global climate neutrality, a rapid market development of wind, solar and green hydrogen production is key.”

Dr. Patrick Graichen
Executive Director, Agora Energiewende

Revolutionizing offshore wind-to-hydrogen systems

Siemens Gamesa and Siemens Energy announced in January 2021 that they are joining forces to kickstart a new era of offshore green hydrogen production that will power a cleaner future[19].

The companies are launching development projects leading to a fully integrated offshore wind-to-hydrogen solution. Siemens Gamesa will adapt its development of the world's most powerful turbine, the SG14-222 DD offshore wind turbine, while Siemens Energy will develop a new electrolysis product for offshore use.

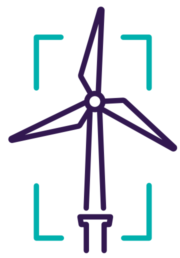
The aim is to join the two developments from each company into an innovative solution that fully integrates an electrolyzer into a dedicated platform at the base of an offshore wind turbine as a single synchronized system, blazing a trail towards offshore hydrogen production. Siemens Energy and Siemens Gamesa target a total investment of approximately EUR 120 million in the development of this innovative solution.

This decentralized offshore wind-to-hydrogen solution will support the mainstream production of green hydrogen at scale in three main areas: enable more and better wind sites to be utilized using island-mode; maximize the amount of wind power that is converted to green hydrogen by reducing transmission losses; and reduce costs further by modularization.

These three factors all contribute towards the economies of scale needed for the cost-effective production of industrial volumes of green hydrogen.

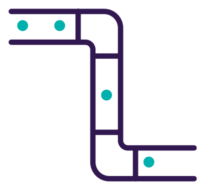
1. Island-mode capability

Today's wind turbines have been developed to accommodate the requirements of being connected to the grid, which puts restraints on the potential available output from each turbine. For dedicated offshore green hydrogen production operating in island mode, each component of the turbine, from the drivetrain to the rotor, will be optimized in a whole new design space. This innovation will also enable dedicated hydrogen-producing wind projects to be sited where wind speeds are the highest, independent of grid connection.



2. Electrical connection

When an offshore wind farm feeds electricity to an electrolyzer facility on land, there are a number of energy conversions which lessen the output. By integrating the co-located electrolyzer with an offshore turbine in an integrated system, the array cables, offshore substation, export cable and onshore substation are substituted with hydrogen transmission in pipes, which entail significantly lower power losses. This results in higher system output of hydrogen per kWh produced at the rotor level.



3. Modular design

The solution will consist of a combination of modular and standardized components. This way, offshore wind energy plants for hydrogen production of various sizes and locations can use the same solution instead of having to build one-off, project-specific installations for each site. The modular set-up means that there are low supply chain impacts - parts can be moved using the same infrastructure – and with less risk - when each turbine is effectively its own hydrogen production plant. A single turbine experiencing a disruption will not prevent the others in the field from working.

Next steps

These innovation developments will serve as a test bed for making large-scale, cost-efficient hydrogen production a reality and will prove the feasibility of reliable, effective implementation of modular offshore wind-to-hydrogen systems.

3 What will it take to make green hydrogen available at scale, at a cost-competitive price and on time?

Key takeaways

To deliver low-cost green hydrogen at scale in the next decade we need to lower the cost, and doing so will require us to:

1. Increase the capacity of renewables. By 2050, it's expected that demand for hydrogen will reach 500 million tons. If the majority of this will be met by green hydrogen, it will require between 3,000 tons and 6,000 GW of new installed renewable capacity, up from 2,800 GW today.

2. Create a cost-effective demand-side market for green hydrogen. Increasing demand will get a green hydrogen economy started, create market size and help lower costs of equipment, infrastructure, operating costs and also lower the overall financing cost.

3. Develop a supply chain. There is not one provider in the market which can take ownership of the entire hydrogen production and distribution process – without working together green hydrogen will remain fragmented, unfulfilled, costly and outside of the energy mainstream.

4. Support the right infrastructure. Logistics, storage and distribution need to be factored into the end-to-end green hydrogen market. There needs to be investment in hydrogen grid networks, whether new or retrofitted, to embed green hydrogen as mainstream energy source.

The wind industry has in the past set ambitious targets and overachieved them. In 2012, the aim was for offshore wind costs to drop below €100/MWh by 2020. But by 2016, with this target in sight, the industry raised the bar and decided that less than €80/MWh by 2025 was more appropriate[20]. Today, offshore wind is already produced at less than this, and further reductions are targeted. The green hydrogen industry will benefit from this ongoing drop in costs.

The innovations that Siemens Gamesa is engaging in have the clear target to reach cost levels that enable a rapid up take of green hydrogen across a number of hard-to-electrify sectors. Using an existing wind power plant to power a co-located electrolyzer with batteries to store surplus energy will accelerate the production of green hydrogen in the short-term. This configuration, being tested at the Brande Hydrogen pilot project site, with the right market framework will help the EU install at least 40 GW of green hydrogen electrolyzers by 2030.

Wind power plant owners with expiring feed-in tariffs or operating in an electricity market characterized by price and demand volatility, are an addressable market for switching to this green hydrogen production method. Wind sites close to existing hydrogen demand centers can also change to green hydrogen production. This not only accelerates the green hydrogen generation, but also adds valuable flexibility to the grid, easing further build-out of electricity-producing turbines. As a result, green hydrogen produced using this type of setup will reach fossil parity by 2030 onshore and 2035 offshore. Fossil parity is understood as a green hydrogen price that equals grey hydrogen with fair CO_2 pricing.

Since the 2050 target of carbon neutrality will require green hydrogen generation at scale, Siemens Gamesa as a technology company will accelerate its efforts to bring a prototype of the offshore wind-to-hydrogen solution to market in the next five years, followed by the first industrial scale wind plant shortly thereafter. If the first 2 GW of offshore wind-to-hydrogen plants are installed by 2030, followed by another 10 GW by 2035, the volumes will provide the scale needed for offshore hydrogen to reach cost parity by 2035.

“In order to reap the full potential of renewable hydrogen, we need to stimulate the creation of a steady flow of new projects to implement the EU hydrogen strategy and deliver on its 2024 and 2030 objectives. We are aware of the challenge this poses and we have a very tight schedule to establish closer cooperation across several industrial sectors. Our stakeholders show very strong commitment and dedication to the creation of an authentic European hydrogen value chain. This will be a major driver for reducing CO_2 emissions in the EU, helping to achieve our energy and climate targets.”

Ditte Juul Jørgensen,
Director General for Energy, European Commission

These are ambitious targets, reflecting the urgency of the climate crisis. The public and private sectors need to work together in the following four areas to create the commercial landscape that supports the roll-out of green hydrogen.

1 Increase the capacity of renewables:

The green hydrogen revolution can only happen if the renewable energy sector delivers on its already impressive growth projections. As things stand, meeting the current demand for hydrogen by switching from fossil fuel to renewables would require 820 GW of wind generating capacity, 26 % more than the current global installed wind capacity. By 2030, analyst reports indicate that 50 GW of onshore and 10 GW of offshore cumulative installed wind capacity will be required to meet green hydrogen demand.

Looking ahead, several studies suggest that by 2050 the demand for hydrogen will be up to 500 million tonnes, assuming that a major share of this will be green hydrogen, requiring between 3,000 and 6,000 GW of new installed renewable capacity, up from 2,800 GW today.

This means to accelerate and massively deploy renewable generation capacity, all stakeholders have a role to play in ensuring that even more renewable energy is generated and made available to end-users. Governments need to plan sufficient volumes and accelerate permitting. The industry needs to ramp up output, production and logistics accordingly.

Boosting renewable energy capacity will have wider environmental and socio-economic benefits beyond green hydrogen.

2 Create a cost-effective demand-side market for green hydrogen:

Today's demand for hydrogen is met almost entirely by fossil fuels, due to cost, availability, and no regulations requiring green hydrogen. Switching production to green hydrogen is an easy win in terms of the impact on the climate.

Increasing demand will get a green hydrogen economy started, create market size and help lower costs of equipment, infrastructure, operating cost and finally lower the overall financing cost.

In all businesses, costs impact demand and green hydrogen is no exception. The current cost profile for green hydrogen is based on legacy processes but will be rewritten over time as green hydrogen becomes mainstream. But hydrogen's presence today also provides an established benchmark against which future improvements in cost, performance, reliability and carbon emissions can be measured.

The main operating cost for green hydrogen production is powering the electrolyzers, so a decrease in energy cost lowers the cost of the hydrogen and increases demand. Initial data suggests energy represents up to 70 % of the hydrogen cost so it's key to bring the costs of renewable energy down further. BNEF's New Energy Outlook 2020 estimates a LCOE reduction of onshore wind between 35 % and 66 % by 2050, setting up the energy cost of a standard unsubsidized project below $ 31/MWh in most major economies[21].

The outlook for the commercial performance of green hydrogen is also related to capital expenditure and utilization rate of electrolyzers. Estimates suggest that the cost of electrolyzers will come down from c.1000 €/kW today to less than 500 €/kW in the coming decade[22]. This will make the case for integrating the electrolyzer with the renewable energy source even stronger, as the key to lowering the cost of green hydrogen will be to get as much utilization of the electrolyzer as possible.

3 Develop a supply chain:

There is not one provider in the market which can take ownership of the entire hydrogen production and distribution process – without working together green hydrogen will remain fragmented, unfulfilled, costly and outside of the energy mainstream.

Electrolyzers, for example, are vital for the future of green hydrogen and as such the most business-critical partnerships and collaborations will involve working with specialists in this area. Innovation is helping to improve the utilization rates, load factors, start-up time and importantly how they can best operate when powered by renewables.

In addition to electrolyzers, this new supply chain will include elements such as equipment for water treatment and hydrogen compression, as well as hydrogen networks. This will be the skeleton of a new sustainable economic sector.

As a rule, the specifics of a supply chain are dependent on the volumes of green hydrogen which are produced. The bigger the scale, the more important the chain.

4 Support the right infrastructure:

Logistics, storage and distribution need to be factored into the end-to-end green hydrogen market. As things stand, there is no dedicated hydrogen grid network to distribute the energy to end-users, as there is for natural gas and electricity. However, there are ambitious plans within Europe to address this – the European Hydrogen Backbone plan was unveiled by eleven European gas infrastructure companies. It foresees a network of 23,000 km of hydrogen pipelines across Europe by 2040.[23]

The ability of the industry to repurpose existing infrastructure can also support green hydrogen's entry into the energy mainstream during the transition. Retrofitting and upgrading existing pipelines to create the Hydrogen Backbone will account for 75 %, or 18,000 km, of the network while only costing half of the total.

Other elements of the infrastructure are ripe for technology-driven improvements. Addressing energy losses not only during production but also during conversion, storage and transportation is one area where innovation is needed.

The compatibility with repurposed pipelines and existing sites is already helping to establish green hydrogen as a mainstream energy source. The cost of hydrogen as a feedstock and as a power source for turbines currently powered by natural gas is already being quantified. Lazard's 2020 Levelized Cost of Energy[24] analysis includes, for the first time, a reference to the costs of hydrogen as a supplemental fuel component for combined cycle gas generation, providing the market with a base from which to gauge future improvements.

4 Time for collaboration, an entrepreneurial mindset and a unified voice on green hydrogen

An extensive network of partnerships and collaborations will drive the green hydrogen revolution. Active buy-in from the entire sector – producers, distributors, wholesalers, hardware manufacturers and software developers, wind and solar farm owners and operators, end-users, government and regional bodies, financial institutions, investors and innovators – is starting to happen.

A unified voice on green hydrogen, one in which all stakeholders agree on, but which allows for market forces, competition, innovation and entrepreneurship to thrive, is also emerging. With so many moving parts involved in the global development of a green hydrogen ecosystem, it is business-critical that the industry embraces collaboration and partnerships.

Over the years, Siemens Gamesa has built successful partnerships to pioneer innovations in floating wind applications, new control systems, service concepts and electrical infrastructure. It has attained its market-leading position through internal expertise and external collaboration.

This approach will help Siemens Gamesa build the best-in-class partnerships to take the green hydrogen movement forward. Its unrivalled ability to produce zero-carbon power from wind gives it an advantage when talking to electrolyzer manufacturers who will also prioritize their efforts on working with the best partner.

Furthermore, a global leadership position in on- and offshore wind power provides a proven track record in servicing, operations and maintenance. The team is already familiar with diverse operating models. Long-term investment in advanced controls, software, diagnostics and digitalization capabilities allows Siemens Gamesa to customize its servicing proposition for the specifics of green hydrogen production.

The potentially bright future for the green hydrogen industry is a positive for Siemens Gamesa but is also great news for the planet. Cutting greenhouse gas emissions from the hardest-to-electrify sectors is now viable using green hydrogen, while the ongoing decarbonization of the world's electricity supply continues. The next decade is mission-critical for the future of Planet Earth, a future where green hydrogen will have a pivotal role.

"Green hydrogen based on renewables could become a game-changer, complementing renewables and modern bioenergy as key pillars of our climate efforts to hold the line on 1.5°C. IRENA's World Energy Transitions Outlook shows the essential to consider hydrogen and energy transition in tandem in the context of a profound electrification and enhanced efficiency of the energy system. Nearly 70% of all the hydrogen consumed by 2050 could be green.

As costs for green hydrogen production fall and renewable electricity becomes the cheapest source of power, green hydrogen could beat fossil-based hydrogen on costs within this decade. But transitioning hydrogen from a niche player to a widespread energy carrier will require action on many levels, including technology, policy and markets.

Enabling policies, public-private sector collaboration and international coordination will be critical to realize the potential of green hydrogen and create a real market for hydrogen. IRENA welcomes the Siemens Gamesa white paper on green hydrogen, and we continue to closely work with our partners to drive a green hydrogen economy in pursuit of industrial, economic and social value creation, including new jobs."

Francesco La Camera
Director-General of the International Renewable Energy Agency

References

[1] https://climate.copernicus.eu/copernicus-2020-warmest-year-record-europe-globally-2020-ties-2016-warmest-year-recorded

[2] https://www.nasa.gov/specials/sea-level-rise-2020/

[3] https://link.springer.com/article/10.1007/s00376-021-0447-x

[4] https://www.un.org/sg/en/content/sg/articles/2020-12-11/carbon-neutrality-2050-theworld%E2%80%99s-most-urgent-mission

[5] https://ember-climate.org/project/eu-power-sector-2020/

[6] Other terms in the market include “grey”, “blue”, “clean” or “fossil-based” hydrogen, none of which are truly zero carbon. Blue and clean hydrogen is produced when carbon capture technologies reduce rather than eliminate the greenhouse gas emissions from existing fossil-fuel based production processes. Grey hydrogen refers to hydrogen produced by coal or natural gas. Green hydrogen can only apply when the electrolyzer is coupled directly to the renewable source such as wind turbine, or if the electricity from the grid can be guaranteed to come from a renewable source.

[7] https://www.iea.org/reports/energy-technology-perspectives-2020

[8] https://www.irena.org/publications/2020/Dec/Green-hydrogen-cost-reduction

[9] https://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf

[10] https://www.agora-energiewende.de/en/blog/eu-wide-innovation-support-is-key-to-the-success-of-electrolysis-manufacturing-in-europe

[11] https://www.irena.org/publications/2020/Nov/Green-hydrogen

[12] https://www.iea.org/reports/energy-technology-perspectives-2020

[13] https://home.cern/science/physics/early-universe

[14] https://www.forbes.com/sites/energyinnovation/2019/10/07/how-hydrogen-could-become-a-130-billion-us-industry-and-cut-emissions-by-2050/?sh=59c2c5bf2849

[15] https://www.iea.org/reports/energy-technology-perspectives-2020

[16] https://ec.europa.eu/commission/presscorner/detail/en/FS_20_1296

[17] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[18] https://about.bnef.com/new-energy-outlook/

[19] https://www.siemensgamesa.com/en-int/newsroom/2021/01/210113-siemens-gamesa-press-release-siemens-energy-agreement-green-hydrogen

[20] https://www.gwec.net/wp-content/uploads/2016/06/160603-FINAL-Offshore-wind-cost-reduction-statement-with-annex.pdf

[21] https://about.bnef.com/new-energy-outlook/

[22] https://www.agora-energiewende.de/en/blog/eu-wide-innovation-support-is-key-to-the-success-of-electrolysis-manufacturing-in-europe

[23] https://gasforclimate2050.eu/news-item/gas-infrastructure-companies-present-a-european-hydrogen-backbone-plan/

[24] https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2020/

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