Focus

Roland Berger

Innovate and industrialize | How Europe's off-shore wind sector can maintain market leadership and meet the continent's energy goals

Innovate and industrialize / *How Europe's offshore wind sector can maintain market leadership and meet the continent's energy goals*

The last decade saw a remarkable rise in offshore wind energy (OWE). This once expensive and immature technology is now cost-competitive with electricity from fossil sources. In fact, many countries now see offshore wind as a key pillar of their decarbonization strategies to meet climate targets. Huge capacity expansions are planned, with the European Union, for example, wanting to develop 300 GW of OWE capacity by 2050 and make it a core component of Europe's energy system.

While pursuing this growth, the European OWE sector must innovate and industrialize to maintain its market dominance. To secure its global leadership, the sector must target the following advancements: converting OWE to hydrogen, developing floating OWE technology and cutting costs.

Hydrogen is now fully accepted as one of the cornerstones of the energy transition. By converting OWE to hydrogen at the source offshore, decarbonization goals can be achieved faster and at lower costs, with more reliable energy delivery and less environmental impact. With floating technology, wind can be harnessed along deeper coastal waters. Floating OWE could even be combined with hydrogen conversion to enable hydrogen production in remote waters known for strong and consistent winds. But to exploit these opportunities, OWE costs need to come down even more than they already have. This can be achieved through technological innovation and industrialization, such as the use of digital maintenance and increased parts standardization.

Global competition poses a serious threat to Europe's OWE dominance, having won first contracts in European waters. To fend off these competitors, European players must act. If they do, they can fortify their position as the world's offshore wind leaders, and build a future above and beyond carbon for their own economies and citizens, and for the planet as a whole.

PAGE CONTENTS

Cover photo Monty Rakusen/Getty Images

Introduction

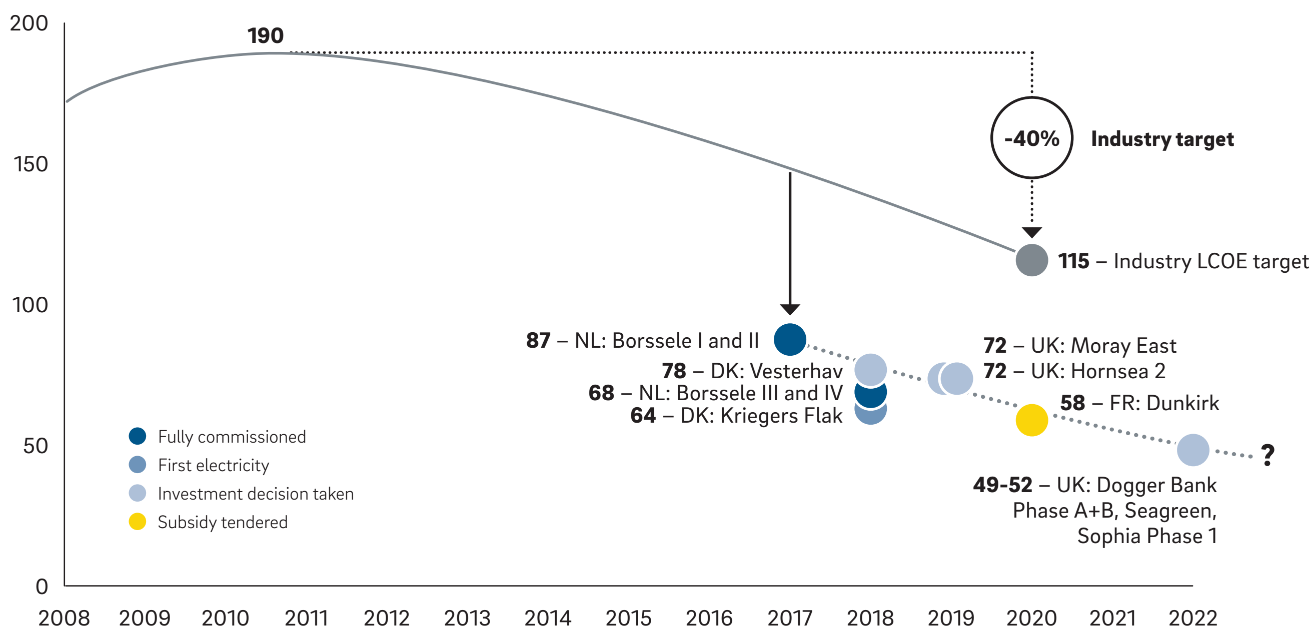
OFFSHORE WIND HAS EMERGED AS A KEY PILLAR OF THE EUROPEAN ENERGY TRANSITION, BUT COSTS STILL NEED TO GO DOWN

Back in 2010, the future of offshore wind energy (OWE) was on a knife's edge. While the technology was considered promising, it was also immature and its costs high compared to other forms of renewable energy. Hefty financing costs, driven by the sector's high-risk status, combined with serious problems in offshore construction and operation, had pushed up the levelized cost of electricity (LCOE) from offshore wind in Europe to around EUR 190 per megawatt-hour (MWh). Something needed to be done, so the industry agreed on a 40% cost reduction target: EUR 115/MWh by 2020.

Developments moved faster than expected. In 2016, the Borssele I and II wind farms, located in the North Sea off the Dutch coast, published a strike price of EUR 87/MWh, significantly lower than the 2020 target. Subsequent projects announced even lower strike prices: prices as low as EUR 49/MWh (including grid connection) have now been achieved, and zero-subsidy tenders have been successful in the Netherlands and Germany.

A: Target achieved

European offshore wind industry confirmed the LCOE reduction with operational wind farms [EUR/MWh]



The industry LCOE target was set by the Crown Estate in 2011: GBP 100/MWh for final investment decision (FID) in 2020. FID is typically 2 years before full operation. To the strike prices, an estimated average of EUR 14/MWh is added for the grid connection. UK strike prices are published in 2012 prices and have been indexed to the year 2018.

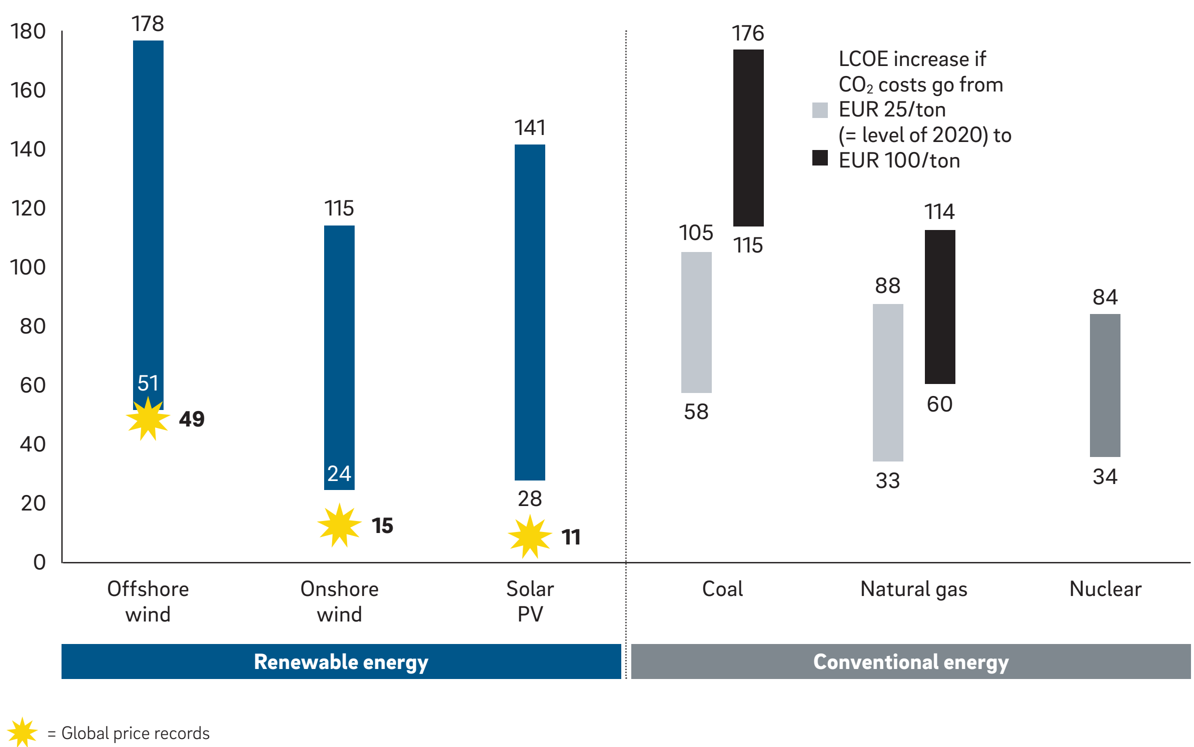
Source: Crown Estate, RVO, press clippings, Roland Berger

Several factors played a role in this rapid progress: a maturing supply chain that is more dependable, experienced and competitive; larger turbines and wind farms; and governments offering more reliable forecasts of upcoming capacity additions, issued in competitive tenders. → A

However, doubts persisted about whether these strike price levels were sustainable. Some observers suspected that these projects were won mainly through aggressive pricing by project developers, and that the supply chain would not be capable of realizing the wind farms at such low costs. Such suspicions proved unfounded: the supply chain has delivered. Several wind farms have taken final investment decisions or achieved first electricity, with the Borssele wind farms fully commissioned in February 2021. Indeed, OWE along the shallow coasts

B: Lean and green

Renewables are cost-competitive with conventional energy, even more so as CO_2 prices increase [Global; 2020; EUR/MWh]



Note: Offshore wind includes grid connection costs of EUR 14/MWh

Source: IEA, Roland Berger

of the North Sea is now cost-competitive with electricity from fossil sources, and becomes even more so when the expected rise in carbon price is incorporated into fossil electricity costs. → B

As a result, ambitions for OWE capacity have risen dramatically. Many governments now see offshore wind as one of the key pillars of their decarbonization strategies to keep global warming below 1.5°C, as agreed in the UN Paris Agreement of 2015. For example, the UK[1] projects 75 GW of OWE, providing 69% of its electricity by 2050, and the European Union wants to develop 300 GW of OWE capacity by 2050 and make it a core component of Europe's energy system[2]. In its recent "Net Zero by 2050" roadmap for the global energy sector, the International Energy Agency called for 80 GW of annual capacity deployment by 2030, up from 5 GW in 2020.

But this surge has seen a rise in low-cost competitors, especially from China, which are threatening Europe's position as market leader. Should Europe's players focus on managing their exponential market growth, or should they also accelerate innovation and industrialization efforts to sustain their lead?

This report addresses precisely this issue. It puts forward and details three targets for innovation and industrialization in the OWE sector. The first is the production, transport and storage of green hydrogen from OWE electricity. The second is the development of floating OWE technologies that can be used along deeper coastal waters and further out at sea. And the third is areas of potential cost reductions in the sector. This report therefore aims to encapsulate what the European OWE sector must do to innovate and industrialize, as well as compete with fast-developing rivals such as China, in order to maintain its dominance in offshore wind.

[1] Source: ORE Catapult, "Realizing the sector deal opportunity", 2019
[2] Source: EU Commission, "An EU strategy to harness the potential of offshore renewable energy for a climate neutral future", Nov. 2020

1 / Green hydrogen

OFFSHORE WIND FARMS CAN PROVIDE HUGE AMOUNTS OF GREEN HYDROGEN, A KEY REQUISITE OF DECARBONIZATION GOALS

The last few years have been pivotal for hydrogen. While its use – either as a direct fuel or in a fuel cell – has long been touted as an alternative to fossil fuels, it has finally broken through and become fully accepted as one of the cornerstones of the energy transition.

Hydrogen's crucial role in moving to a decarbonized energy system comes down to three key attributes. First, hydrogen and its derivatives offer a good option to decarbonize highly energy-intensive sectors such as large-scale transportation and heavy industry (steel, chemicals, etc.). Second, "green" hydrogen produced from renewables can be readily stored in pipelines, salt caverns or depleted gas fields, helping to counteract the effects of renewable intermittency. Third, at higher volumes, energy can be transported at much lower costs by carrying it in molecular form (hydrogen through a pipeline) rather than as electrons (electricity through a cable).

It is for these reasons that hydrogen will play a key part in achieving the world's post-2030 decarbonization goals, and ultimately our total decarbonization. But huge volumes will be required. This is where OWE comes in. Offshore wind is the most suitable renewable energy source in Northwestern Europe for direct coupling of large-scale electricity generation to industrial-scale hydrogen production. OWE capacity expansion plans therefore also need to consider potential conversion of OWE to the large quantities of hydrogen needed for decarbonization goals.

Green hydrogen is produced via electrolysis, and there are compelling reasons to locate electrolyzers offshore at the OWE source rather than onshore:

- **Lower cost:** At high volumes, offshore hydrogen pipelines are cheaper than electricity cables. This differential far offsets the higher cost of producing hydrogen offshore instead of onshore. → C
- **Faster rollout:** The technology and supply chain behind gas pipelines are less complex than those for electricity

cables, which means that the supply chain can scale up faster.

- **Improved reliability:** Offshore gas pipelines are more robust than electrical cables, which can be exposed by sand waves moving along the seabed and damaged, for example, by fishing trawlers.
- **Access to storage:** Offshore-produced hydrogen can be more easily stored in depleted offshore gas fields or salt caverns, avoiding public resistance to onshore storage.
- **Environmental impact:** Offshore gas pipelines have less impact on coastal areas than electrical cables. A single pipeline can transport significantly larger amounts of energy than an electrical cable, thus requiring less disruption of often delicate ecosystems such as the Wadden Sea. What's more, redundant offshore natural gas pipelines can be repurposed to transport hydrogen.

That being said, an onshore hydrogen electrolyzer can be connected directly to the electricity grid, enabling higher electrolyzer capacity utilization. Whether this becomes economically attractive will depend on legislative developments that facilitate green hydrogen

C: Weighing the costs

At larger scale, offshore hydrogen electrolysis is cheaper than onshore hydrogen electrolysis

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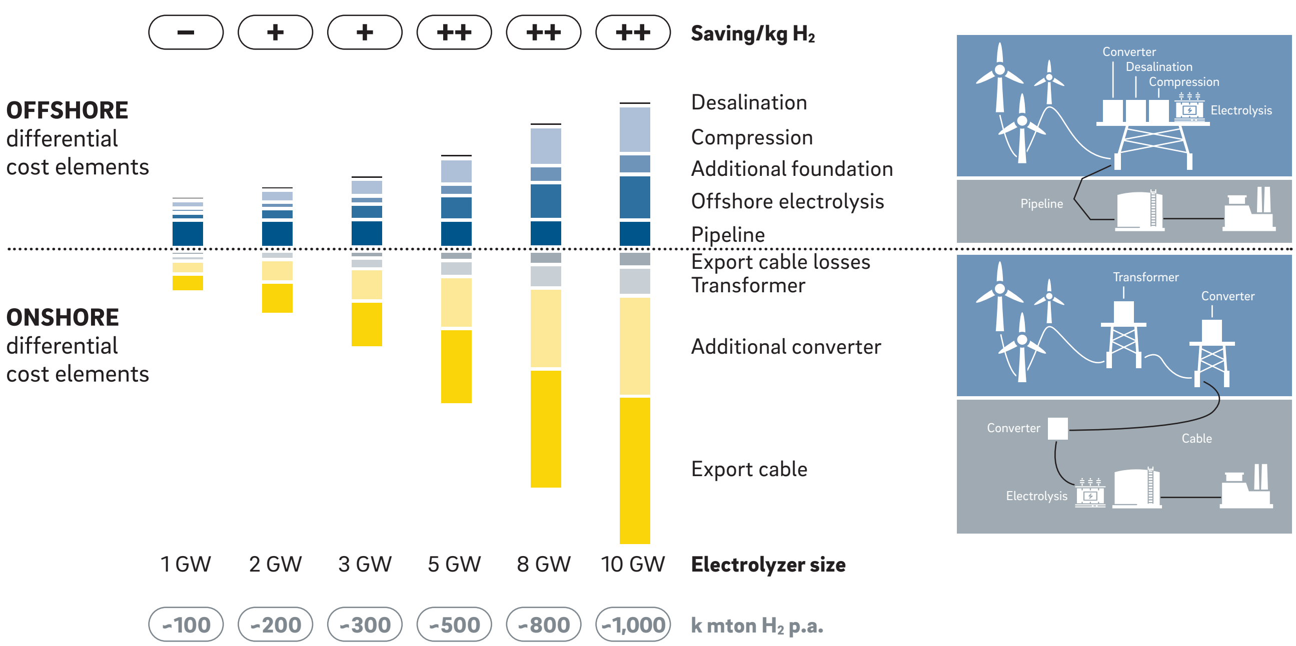

Source: Roland Berger

production with green electricity certificates. The excess heat and oxygen from an onshore electrolyzer can also be monetized if local offtake is available.

NORTH SEA HYDROGEN WILL HAVE TO COMPETE WITH CHEAP HYDROGEN IMPORTS

It therefore seems to be a natural next step to convert large amounts of electricity from OWE into green hydrogen at the source. Offshore electrolyzers can be located on platforms, caissons or artificial islands. They can also be built into turbines. Siemens Gamesa for example, together with Siemens Energy, is working on integrating an electrolysis system into its flagship offshore wind turbine.

The first offshore hydrogen demonstration projects are imminent. Neptune Energy, for example, will soon install a 1 MW electrolyzer on an existing oil & gas platform off the Dutch coast, while the UK Dolphyn wind-to-hydrogen project plans to deploy a 2 MW floating prototype system at the Kincardine site off Aberdeen in 2024. RWE Renewables has initiated the AquaVentus project, which aims to convert 10 GW of additional OWE capacity in the German Bight into green hydrogen by 2035. One of the first AquaVentus sub-projects is dedicated to demonstrating two 14 MW wind turbines – with integrated electrolysis – off the island of Heligoland.

It is expected that green hydrogen from North Sea OWE will cost around EUR 4/kg by 2025. This would make OWE-produced hydrogen competitive with hydrogen shipped from the Middle East, Chile, and other regions where renewable electricity is cheap, for which the cost – including transportation to Europe – is also around EUR 4/kg. However, it is uncertain whether North Sea hydrogen will be competitive in the longer term. As the prime, near-shore OWE locations in Europe fill up, OWE will have to move further out to sea, driving up costs in turn. It is also likely that the costs of vessel transport will go down, putting additional pressure on green hydrogen produced in European waters.

But even at higher costs, hydrogen from European OWE is still likely to remain attractive. Homegrown hydrogen reduces reliance on imports from other regions, some of which are politically unstable. Producing hydrogen at home also allows Europe to capture the downstream value added of hydrogen when it is used as a feedstock, such as in the production of synthetic fuels or green chemicals – value that otherwise moves abroad. → D

Homegrown hydrogen reduces reliance on imports from politically unstable regions. Producing hydrogen at home also allows Europe to capture the downstream value added of hydrogen when it is used as a feedstock, such as in the production of synthetic fuels or green chemicals.

D: The jury is out

By 2025, North Sea hydrogen may be cost-competitive with hydrogen imports from regions with low-cost renewables [EUR/kg H_2]

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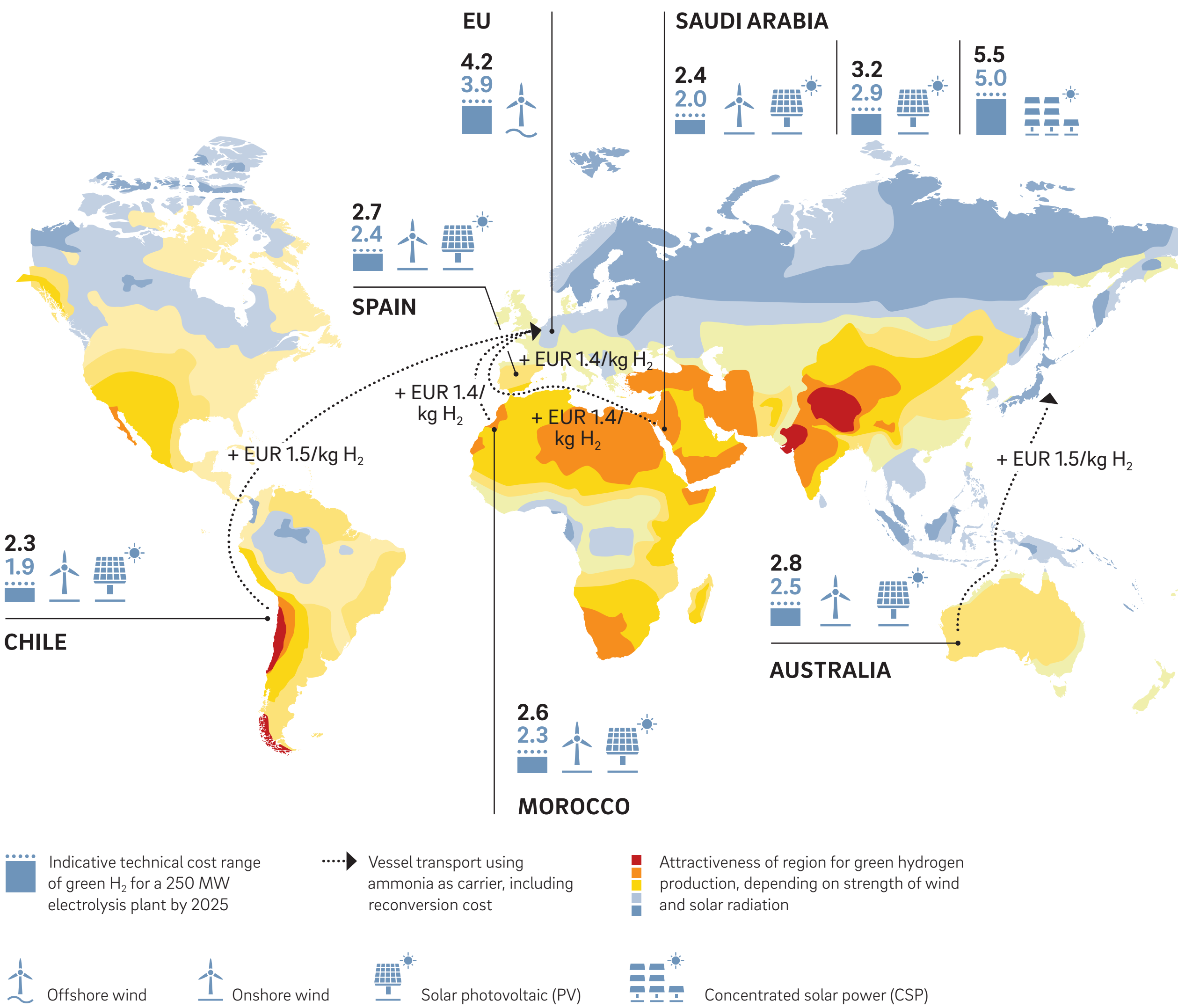


Source: IEA, Roland Berger

2 / Deep-water potential

FLOATING TECHNOLOGY CAN HARNESS WINDS ALONG DEEPER COASTAL WATERS, AND PROMISES EVEN MORE SCOPE FOR CHEAP HYDROGEN PRODUCTION

In Europe, around 80% of the OWE resources are located in waters of more than 60 meters deep, where seabed-based OWE is not economical. This represents a huge untapped supply. Floating OWE technology offers a potential solution, as it allows wind to be harnessed in deep waters. This is especially important for some of the largest potential OWE markets, such as Japan and the West Coast of the United States, where deep coastal waters are unsuitable for seabed-based OWE development. What's more, the technology also allows wind to be harnessed in shallower waters (at a minimum of 30 meters) where the seabed quality makes bottom-fixed OWE economically unviable[3].

Today, floating OWE is still an immature technology. But many large-scale demonstration projects are underway, dominated by European players. Oil and gas companies, such as Equinor, Shell and Total, are particularly active, as they can also use floating OWE technology to electrify and thus decarbonize offshore oil and gas platforms located in remote deep waters. → E

FLOATING TECHNOLOGY PROMISES MORE SCOPE FOR HYDROGEN PRODUCTION

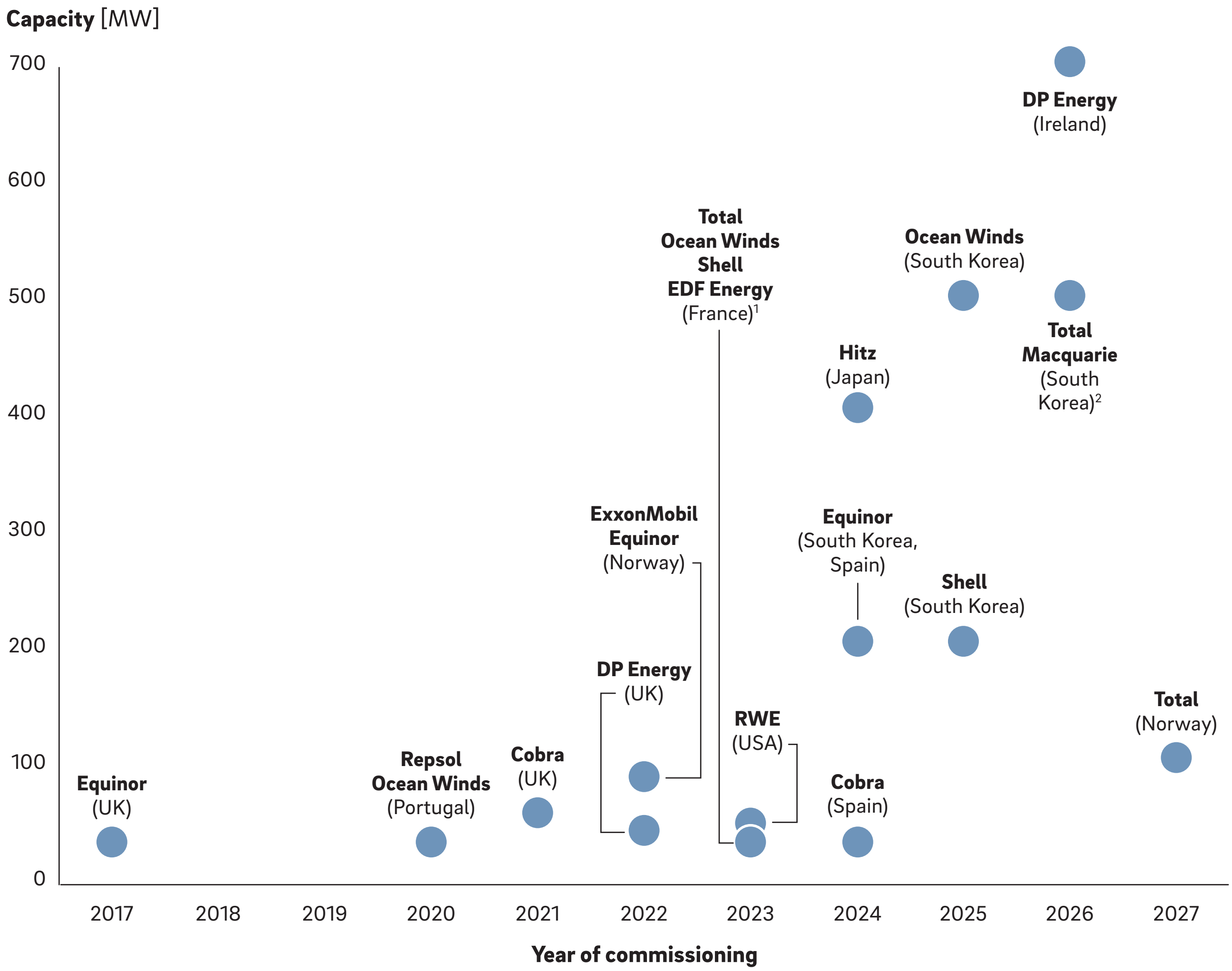
Floating technology makes deep waters accessible to OWE, and, like seabed-based OWE, can be combined with offshore green hydrogen production. For instance, SBM Offshore's floating turbine tension leg design can be anchored at 2,000 meters depth. Electricity generated by floating OWE turbines would be transmitted via cables to a floating production, storage and offloading vessel (FPSO) located close to the wind farm. The electricity would then be converted to hydrogen and stored on the FPSO, and regularly offloaded to a tanker and transported to a port close to large hydrogen demand centers. The advantage here is that FPSO technology is already in use at offshore oil and gas fields in very deep water, and is fully mature, one example being Shell's Turritella FPSO in a water depth of 2,900 meters in the Gulf of Mexico.

Floating OWE technology allows wind to be harnessed in deep waters. This represents a huge untapped opportunity, as large OWE resources in places like Europe, the United States and Japan are located in waters too deep for seabed-based OWE.

It's a conceivable future, where floating technology, green hydrogen and FPSO technology come together to produce very low-cost hydrogen in the most optimal offshore locations, no matter how remote. The seas off the southern coast of Greenland, for instance, boast the strongest and most constant winds on Earth. These so-called katabatic winds blow out from the large and elevated ice sheets of Greenland, generating wind energy capture that is 3.5 times higher than in the North Sea[4]. → F

[3] Source: WindEurope, "Floating offshore wind energy – a policy blueprint for Europe", 2020
[4] Source: Global Wind Atlas

E: Floating ideas
More than a dozen floating offshore wind projects should be commissioned by 2027, with up to 700 MW capacity



1 Several developers have planned to commission floating wind farms with capacity ranging from 25-30 MW
2 Total project has planned capacity of 2 GW, of which 500 MW is planned to be commissioned in 2026

Source: Press clippings

F: Oceans of choice

Hydrogen can be produced offshore either via onshore-linked turbines or at remote floating turbines linked to an FPSO

Floating turbine foundation design: courtesy of SBM Offshore

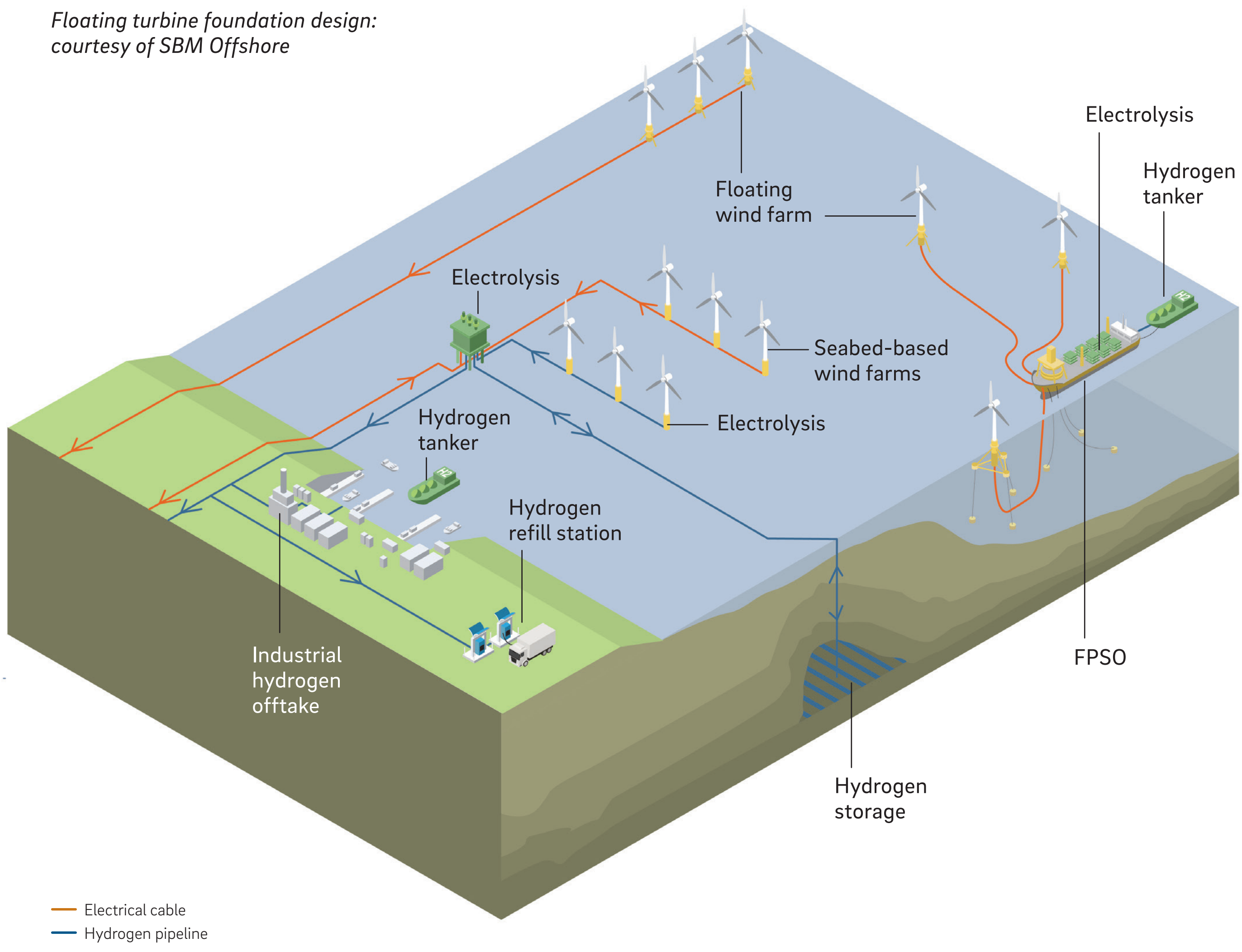


Illustration: DOB-Academy

3 / Cutting costs

REDUCING THE COSTS OF OFFSHORE WIND IS KEY TO EUROPE'S ENERGY INDEPENDENCE AND COMPETITIVENESS, AND INNOVATION AND INDUSTRIALIZATION ARE THE BEST WAY TO DO IT

It's clear that OWE has the potential to produce a large share of the hydrogen required to meet decarbonization goals, and that advances in floating technology will secure access to large swaths of wind power. But one problem remains: costs. Despite hefty cost reductions over the past decade, hydrogen produced from OWE is still relatively expensive. Where OWE is converted to hydrogen, about two-thirds of the cost per kilogram of hydrogen is attributable to OWE itself. Cost reductions in OWE are therefore a major stepping stone for green hydrogen and the role it promises to play in our world's decarbonization targets. And cheaper OWE is also key to Europe's energy independence and industrial competitiveness.

Fortunately, there is clear potential to realize the next step change in OWE cost competitiveness through industrialization and new technologies. Below we look at some examples.

INDUSTRIALIZATION

The OWE supply chain can still benefit from higher levels of industrialization, but this requires the further standardization of parts. Once the industry settles on the maximum turbine size, parts can be standardized throughout the supply chain. Robotizing the assembly of jacket foundations rather than manually welding them could also greatly increase quality and reduce costs. However, to enable such robotization, parts need to be further standardized, and forecasts of upcoming capacity additions need to become more reliable.

LARGER TURBINES

Turbine manufacturers continue to develop ever-larger turbines. GE, for example, has recently upgraded its Haliade model to 14 MW, while Siemens and Vestas have both launched a 15 MW model. Industry experts claim that there is a technical/economic limit to how large offshore wind turbines can ultimately become. However, that limit has not yet been reached, and 20 MW models are already on OEMs' drawing boards.

INTEGRATED DESIGN

The current design of offshore wind turbines and their foundations is still an imperfect marriage between onshore turbine design and offshore oil and gas foundation and installation technology. Smarter integrated designs enable more efficient offshore installation, and thus lead to important cost reductions. Slip joints to connect turbines to their foundations are a recent example. Instead of a time-consuming grouted or bolted connection, the mast of the turbine is simply slid over a conical connector at the top of the monopile, forming a friction-based connection like stacked coffee cups. Another example is the installation of jackets with suction pile technology instead of piles that are hammered into the seabed, meaning lower costs and noiseless installation.

DIGITAL MAINTENANCE

Remote digital structural health and condition monitoring of OWE installations is essential for reducing maintenance costs. This involves generating real-time data about system load and damage to predict maintenance and repair needs of turbines, substations and electrical cables. There is enormous potential here in the development of even more advanced sensors and prognostics algorithms to further reduce the hefty cost of maintenance in harsh offshore conditions.

OPTIMIZED WIND FARM CONTROL

Large-scale aerodynamic interactions within wind farms and between turbines are still not well understood. Simulations and physical models are necessary to get a better grip on these interactions in order to optimize control of the entire array of a wind farm and gain higher energy yields.

SELF-HEALING AND HEALABLE MATERIALS

Manufacturing and maintenance practices have not yet made a full transition from metals to composites. For instance, patching or bolting composite materials is common practice in structural repairs of wind turbine blades. Such practices could be replaced by processable and healable (dynamic) polymeric matrices for fiber composites and/or coatings and adhesives. By using self-repair materials and predictive maintenance approaches from the start, maintenance and repair costs will be drastically reduced over the wind farm's lifetime. → G

THE COSTS OF FLOATING TECHNOLOGY CAN COME DOWN – A LOT

At today's EUR 180-200/MWh for pre-commercial projects, floating technology is expensive. Industry experts predict costs to fall to EUR 80-100/MWh by 2025 and reach EUR 40-60/MWh by 2030 if volumes and industrialization go in the right direction[5]. But there are inherent reasons why floating OWE may become even more cost-efficient than seabed-based OWE in the longer term, despite the higher steel requirements that floating technology will likely entail:

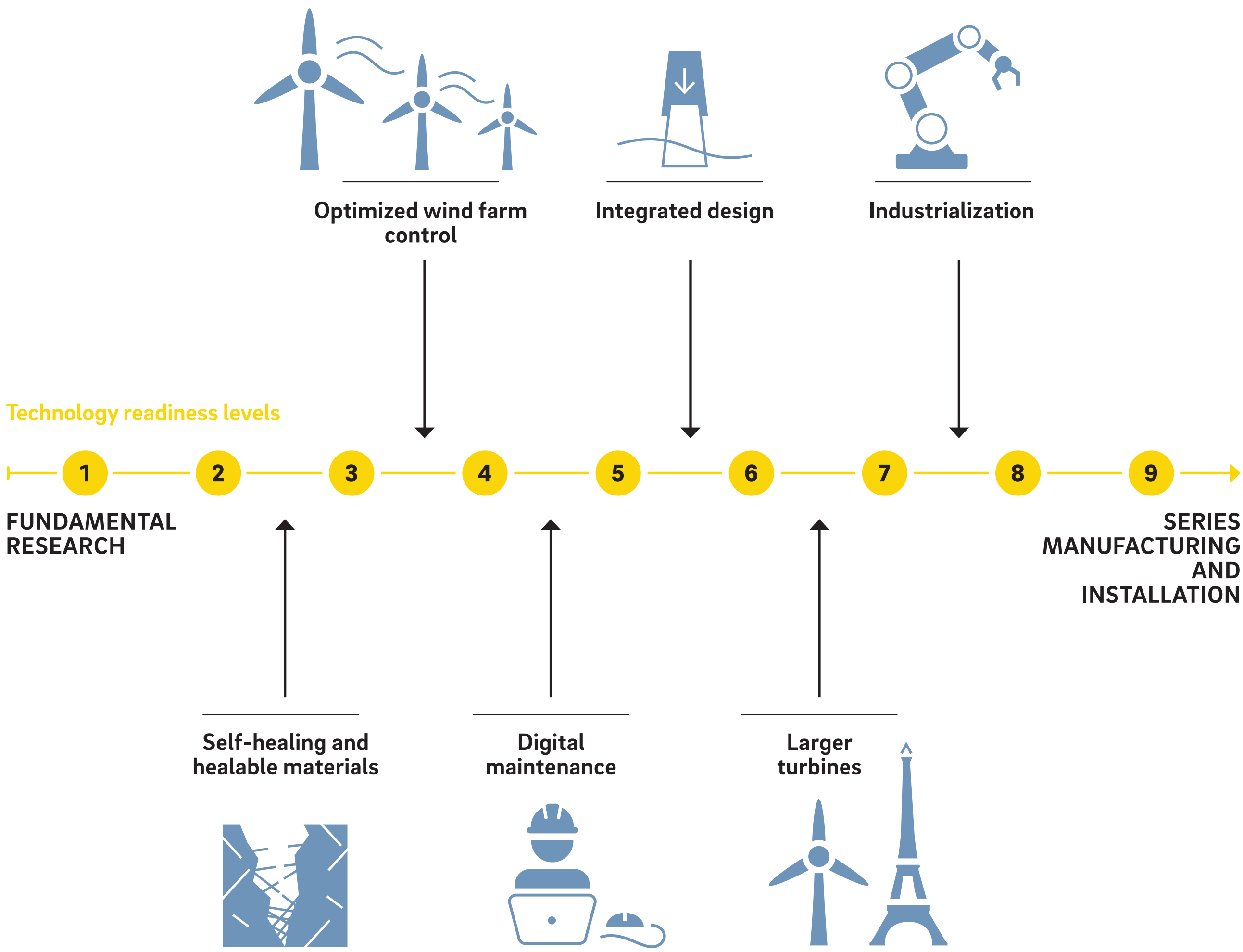
- Floating foundations can be highly standardized because they do not have to be designed for different water depths and soil conditions, expediting industrialization moves.
- Floating turbines can be assembled and pre-commissioned in a harbor and towed as an entire unit to the offshore site by conventional tugs. This means that assembly can take place in a safer, cheaper and more controllable environment. However, for certain floating designs, very deep ports (or fjords) would be needed, which are not always available.
- Turbines can be towed back to port when large maintenance operations – such as blade replacements or gearbox changes – are required.
- All OWE turbines are currently designed for seabed-based foundations. As the market for floating OWE grows, it will become economically interesting to design turbines specifically for floating foundations and to do this using integrated design approaches to reduce costs. Breakthrough innovations will become possible if wind and wave loads on turbine, floater and mooring cables are considered as a single dynamic system[6].

Innovations in offshore wind often require close cooperation between several parties in the value chain. Integrated design optimizations between turbine and foundation, for example, require intensive R&D cooperation between turbine and foundation manufacturers, as well as transport and installation contractors. Europe has ample experience in executing such joint R&D, as proven by successful R&D programs like GROW in the Netherlands and ORE Catapult in the UK.

[5] Source: WindEurope, "Floating offshore wind energy – a policy blueprint for Europe", 2020
[6] Source: The Netherlands' Long-Term Offshore Wind R&D Agenda, 2019

G: Ready or not

Options for OWE cost reductions are at different stages of technological readiness, with industrialization out in front



Source: The Netherlands' Long Term Offshore Wind R&D Agenda, 2019; GROW program; Roland Berger

4 / Innovate and industrialize

EUROPEAN PLAYERS MUST ACT NOW TO FEND OFF COMPETITORS AND KEEP THE UPPER HAND IN THE GLOBAL OFFSHORE WIND MARKET

The worldwide rollout of OWE capacity is led by European companies that developed their products and services in the competitive commercial environment and harsh weather conditions of the North Sea. About 60% of the CAPEX value of global OWE farms commissioned or due to be commissioned between 2020 and 2023 has been captured by European companies. Many of the world's offshore wind farms are being developed by European project developers such as Ørsted, CIP and wpd. Siemens Gamesa, Vestas and GE have strong positions in turbine manufacturing, as do SIF, EEW and Steelwind in foundation manufacturing. In addition, Belgian and Dutch contractors, like DEME and Van Oord, operate internationally in the engineering, procurement and construction (EPC) of offshore wind farms, benefiting from their established global presence in the dredging market. Many other European companies also have strong positions in the value chain.

But despite Europe's dominance, global competitors are knocking on the door. In particular, Chinese companies are becoming more competitive as they learn from their fast-developing home market. Chinese turbine manufacturer Mingyang, for example, launched an 11 MW turbine in 2020. The company also established a business and engineering center in Hamburg, and recently secured a deal to supply turbines to the 30 MW Taranto offshore wind farm off the coast of Italy, its first contract in Europe. Mingyang says it wants to become the "leading global player in offshore wind in the long term".

Such threats stress the need for Europe to act to defend its OWE lead and keep the center of gravity on its shores. There are ominous precedents if European players ignore the warning signs: today, Chinese companies hold an almost 70% market share in the manufacturing of solar PV panels, and around 55% in the manufacturing of onshore wind turbines[7]. → H

About 60% of the CAPEX value of global OWE farms commissioned or due to be commissioned between 2020 and 2023 has been captured by European companies. But Europe needs to act to defend its OWE lead. There are ominous precedents if European players ignore the warning signs.

[7] Source: IEA, GWEC

H: Tight race

European countries are now vying with China for market share in the global seabed-based wind farm sector [2020-2023]

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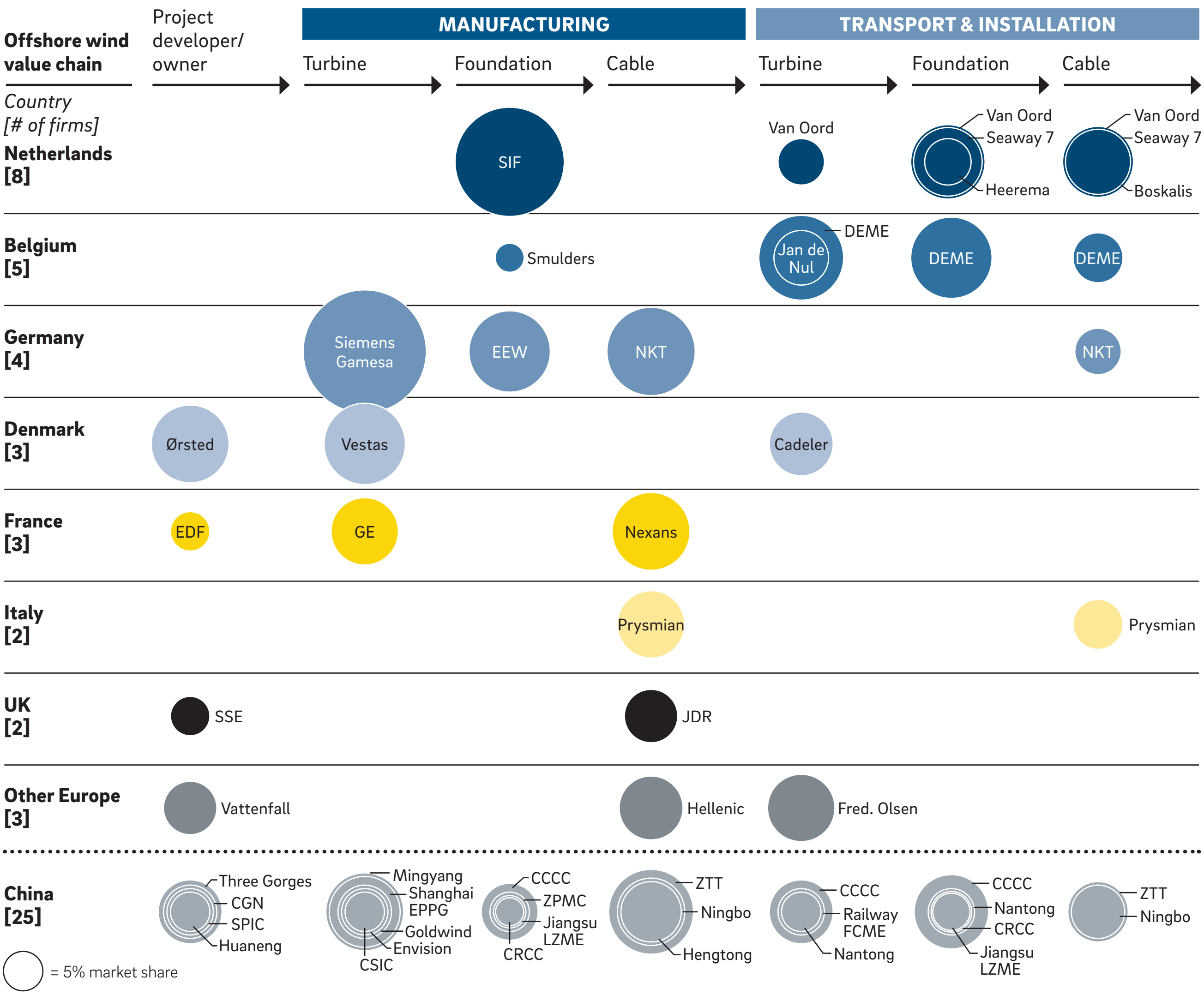


Top 8 per value chain step, measured in installed capacity [MW, (planned to be) operational in 2020-2023]. Companies are allocated to countries based on the footprint of their operations; Lamprell from the United Arab Emirates, the fourth largest player in foundation manufacturing, is excluded as it is not European or Chinese

Source: WindEurope, 4COffshore, Roland Berger

Conclusion

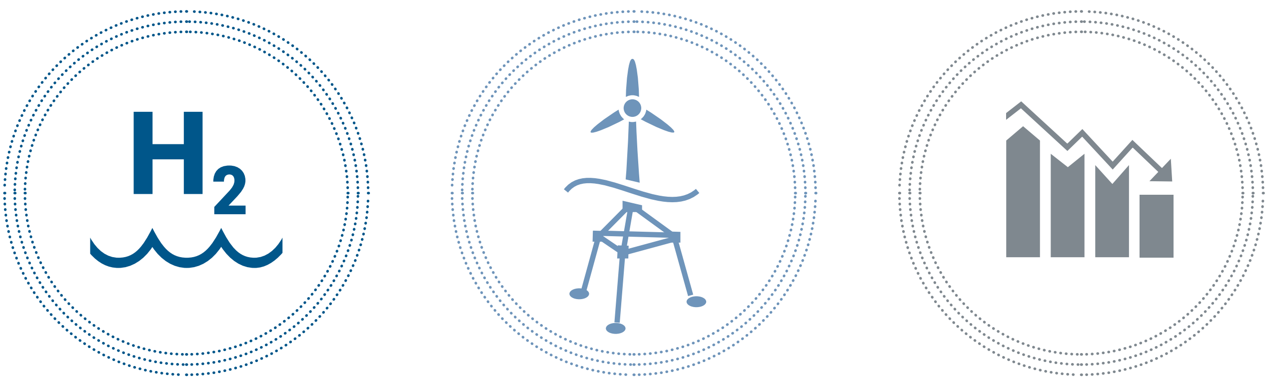
GLOBALLY COMPETITIVE GREEN HYDROGEN AND REDUCED OFFSHORE WIND COSTS GO HAND IN HAND – AND EUROPE CAN SEIZE THE DAY

It is clear that European companies, together with the knowledge infrastructure, must rapidly innovate and industrialize to expand the scope of offshore wind and reduce its costs so that they can cement their place as global leaders. But such advances serve another, more important purpose. Green hydrogen costs are largely dictated by OWE costs, and therefore can be reduced only if OWE costs fall. This makes lower-cost OWE a key requisite for globally competitive hydrogen – and in turn a requisite for Europe's energy independence. Not to mention the fact that competitive green hydrogen costs will create more domestic value in downstream products and enhance the international competitiveness of Europe's energy-intensive industries.

In the coming years, billions of euros will have to be invested in innovation and industrialization to bring OWE to the next level and further reduce its costs. The supply chain can only make such investments if governments and project developers ensure an environment where healthy returns on OWE capacity rollout are possible. This also entails governments facilitating reliable projections of upcoming capacity additions. Combined with the threefold approach proposed here, European OWE can fortify its position as the world's offshore wind leader, building a future above and beyond carbon for its own economies and citizens, and for the planet as a whole. → I

I: Key targets
European offshore wind energy players should focus on three key innovation and industrialization areas until 2030

DEVELOP OFFSHORE HYDROGEN | DEVELOP FLOATING OWE TECHNOLOGY | REDUCE OWE COST FURTHER



Source: Roland Berger

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06.2021

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PUBLISHER:
ROLAND BERGER GMBH
Sederanger 1
80538 Munich
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RB_PUB_21_011