

Offshore wind turbine market developments in The Netherlands

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1 Introduction

TKI-Wind op Zee (TKI-WoZ) has commissioned DNV GL to perform a study into the market developments for offshore wind turbines in The Netherlands /1. This report is the final deliverable.

The report is structured in five sections:

- Section 2 – reviews the current (global) market for (offshore) wind turbines and key sub-components
- Section 3 – discusses existing Dutch capability in the offshore wind sector
- Section 4 – looks to the future and reviews potential innovations in turbine technology that are expected to drive down the cost of energy, considering for each the potential technical challenges which need to be resolved and identifying any potential synergies with Dutch capability.
- Section 5 – discusses the different options for R&D funding, with a particular focus on the best route for bringing forward innovations in those areas with Dutch capability.
- Section 6 – concludes the report, synthesising the analysis and identifying a road map for TKI-WoZ.

This market and technology study focusses on offshore wind and on the turbine and its key components; minor components, sub-components and auxiliary systems, as well as those aspects that purely concern onshore wind and everything below the tower base flange are thus out-of-scope. Further, the assembly and logistics aspects are assumed to be onshore only, directly related to the production of the turbine nacelle, blades and tower. Offshore operations (transport, installation, commissioning, O&M) are out-of-scope.

2 Current Market

2.1 Wind turbine OEMs

The wind turbine generator (WTG) original equipment manufacturers (OEMs) are expected to be the driving force behind most of the innovations out to 2030.

2.1.1 Leading players

As shown by Figure 2-1, within the offshore wind market, Siemens are the clear market leader having delivered around two thirds of the turbines installed to date. Vestas (now MHI Vestas) are in second place. Other leading European OEMs are Senvion (formerly Repower), Areva (now Adwen, a 50-50 joint venture of AREVA and Gamesa) and ALSTOM (expected to soon be GE ALSTOM). There are also a number of Chinese players including Goldwind, Sinovel, Ming Yang and XEMC Darwind.

As can be seen by the number of name changes the market has seen significant consolidation over the past 24 months. Recent developments include:

- MHI Vestas joint venture
- Areva Gamesa joint venture
- ALSTOM GE merger (pending regulatory approval)
- Senvion being sold by Suzlon to a private equity house (Cambridge)
- Samsung entering the market but pulling out.
- Doosan entering the market but pulling out.

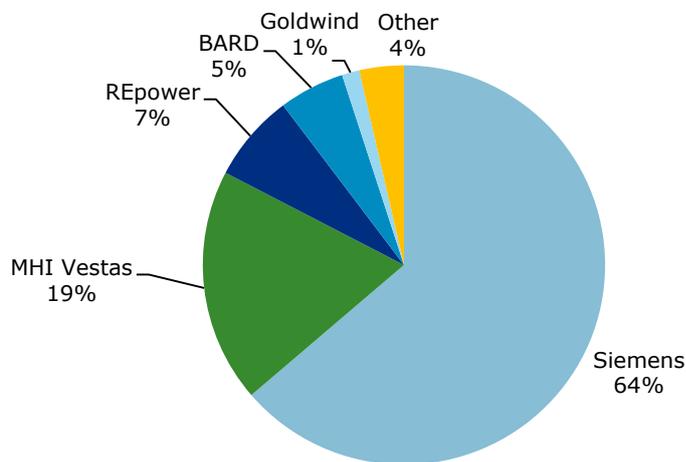


Figure 2-1 Current global installed capacity by OEM [source: DNV GL analysis 2014]

2.1.2 Assembly and manufacturing facilities

The location of the leading European OEM nacelle assembly and blade manufacturing facilities are shown in Figure 2-2. As can be seen none are within the Netherlands.

OEM	Nacelle	Blades
Siemens	Current – Lindo, Denmark	Current – Aalborg, Denmark
	Under construction – Hull, UK	Under construction – Hull, UK
MHI Vestas	Current – Lindo, Denmark	Current – Isle of Wight, UK
	Future - tbc	
ALSTOM	Under construction – Saint Nazaire	Under construction – Cherbourg, France (in partnership with LM Blades)
Senvion	Current – Bremerhaven, Germany	Supplied by PowerBlades – Bremerhaven, Germany
Areva	Current – Bremerhaven	Blades – Stade, Germany
	Future – Le Havre (tbc)	

Figure 2-2 Location of current and future nacelle assembly and blade manufacturing facilities

2.1.3 Outlook

The offshore wind market in the EU has seen a number of downgrades of future capacity projections with DNV GL expecting there to be sufficient remaining market demand to support around 3-5 WTG OEMs, subject to demand in the post 2020 period being of similar scale to pre 2020 period. Siemens looks set to remain market leader for a while, picking up four orders in 2014 (at Dudgeon, Sandbank, Gemini and Westermeerwind). These recent orders are in addition to the large framework contracts Siemens have with DONG, with 1.8GW of 6MW turbines expected to be installed in the UK between 2014 and 2018 and 934MW at Gode Wind in Germany.

MHI Vestas were the only other OEM to pick up a major order in 2014, signing the first commercial agreement for the new 8MW-164 with DONG at the Burbo Bank Extension. The extremely high technical and financial barriers to new entrants and reduced volume expectations mean that it is highly likely that those currently leading the market will continue to dominate, at least in the medium term.

Beyond Europe, the Chinese offshore wind market picked up in 2014 and there is now policy momentum to achieve the revised target of 10GW by 2020 (from a base of a little over 500MW at the end of 2014). This very rapid increase in capacity implies that Chinese OEMs should be expected to be focused on the Chinese market out to 2020. This, combined with the need for a strong track record, suggests that Chinese OEMs are unlikely to enter the European market until post 2020.

2.2 Components

Offshore turbine OEMs generally undertake substantial research, design and production work in-house, not just at the turbine system level, but also at the level of components. Despite this, a substantial market has been established for 3rd party component supply in offshore wind, building upon the supply chain for onshore turbines.

This chapter makes use of publically available information to identify the current supply chain actors for four key components; wind turbine blades, gearboxes, generators and bearings.

2.2.1 Blades

While many of the largest wind turbine manufacturers such as Vestas, Siemens, Enercon and others operate their own blade development and manufacturing facilities, there is still a range of competing independent companies who are able to supply blades for multi-MW turbines. Many of these companies are also leading the way in the development of larger next generation blades, using ever more sophisticated materials and manufacturing techniques.

The following list describes companies with manufacturing capabilities for multi-MW turbines. Design houses without manufacturing capability have not been included.

Blade Dynamics

[<http://www.bladedynamics.com/>]

The UK based blade developer Blade Dynamics was founded in 2007. The company's design and manufacturing operations are focused on wind turbine blades using a seamless modular assembly technology. This approach has resulted in the development of a number of patents and a 49m blade for 2.5MW machines, which at 6 tons is reported to be the lightest in its class.

Because the blades can be transported in sections, the technology is intended to resolve current limits on rotor diameters, whilst also minimising weight. The first large-scale prototype blade based on this new design was statically tested in 2009 and the first full scale blade was finished in 2010.

In 2013, the company was awarded a large contract by the UK's Energy Technology Institute (ETI) to develop and prototype the next generation of offshore wind turbine blades with lengths between 80 and 100 meters. Siemens Wind Power announced the support to the project, aiming the use of the blade for its SWT-6.0 turbine. After a period of prototyping, the blades were expected to enter full production towards the end of 2014. The company is also presently working on high performance blades for 7MW offshore machines.

In December 2014, the company was also awarded £1m by Process Technology Innovation Funding under the GROW: Offshore Wind Program for their Advanced Blade Tip development project, which is due on the second quarter of 2015.

The business has facilities in the Isle of White, UK and Louisiana, USA.

EUROS

[<http://www.euros.de/en/company.html>]

EUROS was founded in 1996 in Berlin as a development office for rotor blades and since 2000 has been delivering rotor blades to various turbine manufacturers worldwide. EUROS has developed and manufactured more than 20 different rotor blade types. Installed power in 2011 was 400MW. Their product line ranges from the EU20, a 9.5 m long blade for 100 kW passive stall turbines, to the M-EU167, a 81.6 m long blade designed for the Mitsubishi's 7MW Sea Angel offshore turbine.

EUROS offer rotor blades, licenses and technology transfer. Their strategy is to exploit cost effectiveness of commonality by designing blades in families. The centre section is identical within one family, whilst root and tip segments can be designed to meet customer specifications.

The customized multi-MW wind turbine rotor blades are developed in Germany, manufactured in Poland and Germany and delivered within and outside Europe.

LM Wind Power

[<http://www.lmwindpower.com/>]

In April 2010, LM Glasfiber became LM Wind Power. Their businesses comprises of LM Wind Power Blades, LM Wind Power Service & Logistics, and Svendborg Brakes (divested in 2013).

LM Wind Power is the world's leading supplier of rotor blades to the wind industry. The company has supplied more than 175,000 wind turbine blades in 35 years, corresponding to approximately 70 GW installed. This equates to approximately one fifth of all wind turbines being powered by LM blades. Customers include Gamesa, Vestas, Siemens, Alstom, Suzlon and Sinovel.

The company is headquartered in Denmark with a global business office in the Netherlands. Their manufacturing capacity includes factories located in thirteen locations in 8 countries over four continents; in Canada, USA, Brazil, Spain, Poland, Denmark, India and China.

The LM 61.5 P2 is the longest wind turbine blade in serial production designed for 5-6MW turbine capacity. They have also developed a 73.5 meter blade, which was developed in collaboration with Alstom specifically for the Alstom's Haliade 150-6MW wind turbine, first installed in March, 2012.

Features on LM's blades are divided into standard features and add-ons, which are developed in consultation with customers. Add-ons include their new insulated lightning protection system called SafeReceptors, leading edge tape for reliability and vortex generators on the surface of the blade to maximize performance.

SINOI GmbH (formerly NOI)

[<http://www.sinoi.de/home/>]

In 2006, SINOI a wholly owned subsidiary of the Chinese Lianyungang Zhongfu LianZhong Composites Group Co., Ltd. (LZFRP), acquired the assets of NOI Rotorteknik.

SINOI has an annual production capacity of 10,000 rotor blades, with production facilities in Nordhausen (SINOI GmbH, Germany), Lianyungang (Jiangsu Province, China), Shenyang (Liaoning

Province, China), Baotou (Inner Mongolia, China), Jiuquan (Gansu Province, China), Hami (Xinjiang Province, China) and Bijie (Guizhou Province, China).

The company's rotor blade production ranges from 34m blades rated for 1.5MW turbines to a 62m long blade for 5MW machines.

The company has an agreement with Aerodyn to manufacture their "aeroBlade" designs. These consist of blades ranging between 34 to 50.3 m in length for 1.5 MW, 2.0 MW and 2.5 MW turbine designs.

Production of the 62m blade started in Lianyungang, China in December 2010. The blade was developed in partnership with China's wind turbine manufacturer Sinovel for their 5 MW SL5000 machine. Class 2 and 3 rotor blades are apparently also in development for the 5 MW rating.

The company has also developed their S150.3 rotor blade in collaboration with the Finnish wind turbine manufacturer WinWinD for its 3-megawatt wind turbines.

SSP Technology

[<http://www.ssptech.com/>]

SSP is a Danish company founded in 2001. They design, develop and optimise wind turbine blades. They offer turnkey production concepts including blade design, tooling and mould manufacturing, production of test blades, prototype blade set and execution of static and fatigue testing.

SSP developed the 83,5 m blade for Samsung Heavy Industries' new 7 MW wind turbine. They have manufactured more than 40 moulds, and designed and developed more than 15 unique blades.

TECSIS

[<http://www.tecsis.com.br/>; <http://www.rechargenews.com/wind/1396793/tecsis-plans-blade-factory-in-us-or-europe-as-it-outgrows-brazil>; <http://www.compositesworld.com/news/reported-wind-turbine-blade-breaks-apparently-involve-carbon-spars>]

TECSIS (Tecsis Tecnologia e Sistemas Avançados) has been a supplier of blades to the wind energy sector since 1995 and is understood to be the second largest manufacturer of wind turbine blades. The Brazilian company is known for its large contracts with GE, but has also supplied Alstom, Gamesa, Impsa, and Siemens.

Despite having a concentrated manufacturing footprint in Brazil, with an annual capacity of 8,000 blades, TECSIS claim to have over 40,000 blades operating in over 10 countries, of which more than 36,000 are installed on wind turbines rated 1MW or greater. The company has plans to open a factory in US or Europe in 2018.

They develop new blade designs specific to customers' requirements and also offer customers the possibility translating their own designs to volume production. TECSIS declare that they are able to put a new design in to production volumes of 200+ blades/month in less than 6 months. The length of the TECSIS blades varies from around 37 to 50m.

TPI

[<http://www.tpicomposites.com/>]

TPI Composites originated as a boat builder over 40 years ago, but today manufactures advanced composites for the defence, transportation and the wind industry. To-date the company has manufactured more than 10,000 wind blades over ten years. They have provided blades up to 48m length to Mitsubishi and GE for machines rated at 2.4MW. In 2014, TPI signed a long term agreement with Gamesa to supply blades for its G114 wind turbine.

The company has Corporate Headquarters in Scottsdale, AZ (USA), a development and manufacturing facility in Warren, RI (USA), and other five manufacturing plants located in Newton, IA (USA), Fall River, MA (USA), Ciudad Juarez (Mexico), Izmir (Turkey), Jiangsu and Taicang (China). They state that they work with their partners to select manufacturing sites that are “local” to the market in order to optimize transportation and labour costs. Examples of this are the facilities in Taicang and in Newton, established to manufacture GE blades under a long-term supply agreement; and Gamesa’s blades to be manufactured in Ciudad Juarez.

Others

Other blade manufacturing companies that have not yet entered the offshore market are for instance *Aeris* and *MFG*.

Aeris is a newly established independent blade manufacturing company located in the Brazilian state of Ceará. The Ceará facility was set up in collaboration with the wind turbine manufacturer Suzlon which is reported to have started serial production of blades for the Suzlon S95 wind turbine from July 2012. *Aeris* provides the option of manufacturing blades designed by partnering with engineering offices as well as manufacturing of blades developed by their customer. The company is preparing to produce blades up to 60 meters in length, but says that current facilities could offer capacity for blades of up to 70 meters length.

MFG is a USA company that has produced over 9,000 blades for over 25 years, with clients including GE. Currently they have two blade manufacturing facilities in mid- USA. Even though their location is not near coast lines, they claim to be working on innovative new designs for both onshore and offshore turbines.

Manufacturer	Largest blade size [m]	Associated Machine Size [MW]	Track Record ¹
LM Wind Power	73.5	6	
TECSIS	50	-	***
SINOI	62	5	**
EUROS	81.6	7	***
Blade Dynamics ²	49 ¹	2.5 ¹	*

¹ *** = delivered large series offshore over several years, *= experience is limited to prototype blades or small series only

² in addition, Blade Dynamics works on a blade prototype of 78m for the Siemens 6 MW turbine

TPI	55.5	2.0	**
SSP	81.6	7	*

Table 2-1: Summary of blade market participants

2.2.2 Gearboxes

The wind turbine gearbox supply chain, particularly as it relates to multi-megawatt turbines, is dominated by a few key players.

Whilst this study has identified nine suppliers with the capability to supply gearboxes for multi-megawatt wind turbines, two of those suppliers, namely Winergy and ZF Wind (formally Hansen), are understood to account for the majority of the market share of gearboxes for turbines greater than 1.5MW.

Notwithstanding this situation, there would be a good choice of suppliers capable of supplying a turbine gearbox for a large offshore turbine. Design houses without manufacturing capability have not been included.

Bosch-Rexroth

[<http://www.boschrexroth.com/en/xc/products/product-groups/gear-technology/gearboxes-for-wind-turbines/index>]

As a well-established supplier of gearboxes, hydraulics and pitch and yaw drives, Bosch Rexroth are known for having supplied gearboxes to Vestas, GE Energy and Nordex.

Bosch Rexroth has established a total of four production facilities, two in Germany (Witten and Nürnberg) and China (Beijing).

Their portfolio of gearboxes offers solutions for up to 3MW capacity, but according to correspondence received from the firm, they have projects on the drawing board which go up to 10MW. In May 2015 ZF Wind announced that it has acquired the large gearbox business of Bosch Rexroth.

David Brown

[<http://www.davidbrown.com/>]

David Brown was acquired first by Clyde Blowers in 2008, and later in 2013 Moventas (also owned by Clyde Blowers) acquired David Brown.

David Brown had been engaged by Clipper Windpower for the supply of the gearboxes to be used in the Britannia 10MW turbine prototypes scheduled for deployment in late 2011. However, following failure of Clipper to meet certain development milestones and subsequent cancellation of government support, the project was cancelled in 2011. In February 2012, David Brown confirmed the signing of a contract with South Korean company Samsung Heavy Industries (SHI) to design and manufacture of the gear system for their 7MW prototype turbine.

Whilst not having a wide footprint as gearbox manufacturer in the wind industry they are one of the larger gearbox service suppliers in the wind industry. David Brown is also a recognized supplier of transmission systems to heavy industry.

David Brown has manufacturing facilities located in Australia, China, Canada, France, South Africa, UK and USA.

Facilities in the UK are capable of prototype development and testing through to serial production for gearboxes in the 5MW to 10MW range.

Eickhoff

[<http://www.eickhoffwindenergy.com/>]

Eickhoff started manufacturing gearboxes for the wind turbine industry in 1992. Since January 2009, Eickhoff have manufactured the Eicogear wind turbine gearbox series from their machining plant, located on the outskirts of Dresden, Germany. The Eicogear product range is suitable for wind turbines between 1.5MW and 3.8MW capacity.

Eickhoff is understood to have an existing supply chain relationship with GE Energy, Nordex and Senvion.

Ishibashi

[<http://www.ishibashi-mfg.com/en/product/product1.html>]

Ishibashi is the largest wind turbine gearbox manufacturer in Japan. They started producing wind turbine gearboxes in 1998. Ishibashi has established production facilities in Japan, China and the US; has a large-scaled cold chamber, and has load operation testing facilities up to 5MW, with plans of doubling the capacity in the near future.

Ishibashi produces wind turbine gearboxes ranging from 600 kW up to 5MW

Moventas

[<http://www.moventas.com/>]

Finnish gearbox manufacturer Moventas was acquired by Clyde Blowers (also owning David Brown) late 2011.

Moventas produced its first wind gearbox in 1980 and has supplied gearboxes to major wind turbine manufacturers such as Areva, Acciona, GE, DSME, Repower, WindWinD and Vestas amongst others.

Their gearbox product range includes conventional and hybrid types, as well as their own FusionDrive concept (co-developed with The Switch), an integrated drive train solution combining gearbox and generator in one unit.

The FusionDrive is based on a gearbox platform which Moventas state to be available from 3MW and 7MW capacity.

Moventas has the headquarters and two manufacturing facilities in Finland. It has other manufacturing facilities in Germany and China; a gear assembly facility in Portland, USA; testing facilities for gearboxes up to 10MW and a climatic chamber.

Renk

[\[http://www.renk-testsystem.eu/testsystem/home.html\]](http://www.renk-testsystem.eu/testsystem/home.html)

Production takes place in three plants in Germany and associated plants in France, Switzerland and the USA.

Renk has patented the Aerogear, the first planetary drive with stationary planets in series production. In 2002, Renk established the use of hydrodynamic slide bearings in offshore wind turbine drives for 5MW.

The Renk group also includes a company dedicated to testing; Renk Tests Systems GmbH. It develops test systems for automotive, rail, aircraft and defence industries as well as test systems for complete wind turbines and drive train components. Electric motors and/or mechanical closed-loop-systems allow testing up to 20MW.

Voith Turbo

[\[http://voith.com/en/products-services/wind-energy-378.html\]](http://voith.com/en/products-services/wind-energy-378.html)

In 2005 Voith Turbo started the development of their WinDrive technology with DeWind as partner and commissioned the first 2MW prototype (DeWind 8.2) in 2007.

The system consists of a hydrodynamically controlled superimposed planetary drive, which transforms variable speed input torque into constant speed output torque. In turn, the WinDrive is based on a machine named Vorecon that was developed by Voith in the 1980s and which has been used in a variety of applications, including the offshore oil & gas industry.

The Voith gearbox with variable transmission ratio needs to be combined with a main gearbox. The Voith drive is placed in between the main gearbox and the constant speed generator which is connected directly to the grid.

Voith Turbo has started development of the system for Bard Engineering, Lanzhou Electric Corporation and Guodian United Power. Installation of a 6.5MW prototype unit for Bard took place in February 2011, but according to Voith Turbo, they can provide the WinDrive technology for applications up to 20MW capacity.

Voith has capability for dynamic testing of drive trains up to a capacity of 9 MW.

Wikov – Orbital2

[\[http://www.wikov.cz/en/mechanical-gearboxes/according-to-application/wind-and-tidal\]](http://www.wikov.cz/en/mechanical-gearboxes/according-to-application/wind-and-tidal)

Based in the Czech Republic, Wikov encompasses a design house (Orbital 2) and manufacturing capability (Wikov MGI).

Wikov has manufactured gearboxes for 3MW turbines, for Doosan, Sinovel, Sewind and is currently manufacturing 5MW gearboxes for Dong Fang.

Their gearbox portfolio includes conventional planetary/helical and two-stage planetary types for multi-MW class. All planetary gearboxes apply flexible pin multi-satellite technology.

Wikov have also developed variable gear ratio technology for gearboxes (super position gear - SPG) and applied this patented system to their 2MW gearbox.

Wikov has capabilities to carry out load and cold chamber tests.

Winergy

[<https://www.winergy-group.com/cms/website.php?id=/en/products/gearboxes.htm>]

Since starting producing gear units for wind turbines in 1981 and with manufacturing facilities in Germany, USA, China and India, Winergy have supplied gearboxes to key turbine OEMs that include Vestas, Nordex, Siemens, GE, Repower, Suzlon, Gamesa, Acciona, Alstom and Bard. Winergy was acquired by Siemens in 2005, but both companies continue to trade independently from one another.

Winergy offer complete drive train and power system solutions including gearbox, couplings, generators and converters. Their gearbox portfolio includes conventional planetary/helical stage types for up to 6MW, their Multi Duored gearbox for 6.5MW, which according to Winergy is scalable for up to 12MW, and the HybridDrive integrated gear and generator unit.

Their testing capability is based on a range of 13 test benches across all production facilities with a maximum capacity of 14MW.

ZF Wind (formerly Hansen Transmissions)

[http://www.zf.com/corporate/en_de/products/product_range/wind_power/index.html]

Hansen was acquired by ZF Friedrichshafen AG in December 2011. Hansen started manufacturing gearboxes for wind turbines in 1979 and since then has established production facilities in Lommel (Belgium), Coimbatore (India), Tianjin (China) and Gainsville (USA). Hansen has supplied gearboxes to most major wind turbine manufacturers (including Vestas, Gamesa, Siemens, Suzlon, Repower and Sinovel). ZF Wind have acquired the large gearbox business of Bosch Rexroth in May 2014.

Their multi-megawatt portfolio includes conventional 4-point support drive train gearboxes for up to 6MW, a hybrid solution (integrated rotor support) for 3MW, as well as an integrated rotor/main bearing/generator 2-stage gearbox concept for application with medium speed generators up to 6MW.

ZF's testing facilities include a dynamic test-bench for gearboxes with a 13.2MW capacity and a dynamic test rig for gearbox bearings.

Manufacturer	Largest Product (MW)	Track Record ³	Testing Capacity (MW)
Bosch Rexroth	3	***	not known
David Brown	7	*	10
Eickhoff	3.8	**	not known
Ishibashi	2.5	**	
Moventas	7	***	10
Renk	5	*	20
Voith Turbo	6.5	*	9
Wikov Group	7	**	8
Winergy	6.5	***	14
ZF Wind	6	***	13.2

Table 2-2: Summary of gearbox market participants

2.2.3 Generator

The high speed Doubly Fed Induction Generator (DFIG) continues to represent the largest fraction of the market.

High and medium speed Permanent Magnet Generators PMG are gaining market share though, where the latter is particularly popular for the largest machines in the market. High speed generators refer to a generator rotational speed of between approximately 1500 to 1000 RPM, the lower number associated with the largest machines at or above about 5MW. The rotational speed of medium speed generators is approximately 300 – 500 RPM.

The development of direct drive turbines has also expanded significantly in recent years, with a number of machines at various ratings being produced. The supply chain now includes in-house manufacturing of in-house designs, outsourced manufacturing of in-house designs, and commercial electrical machine companies providing both design and manufacturing. There are also a number of small companies entering the market offering designs.

The design of a direct drive generator for a particular turbine requires significant interaction between the generator design team and the turbine manufacturer to provide an optimized solution.

The following companies have the design capability and a level of manufacturing experience that would enable them to supply a generator for a large offshore turbine.

ABB

[<http://new.abb.com/windpower>]

ABB provide Doubly Fed (DF), Permanent Magnet (PM) or Squirrel Cage (SC) rotor options for their high speed generators, which are all based around a standard drive train design. The common design allows the option to convert between DF and Full Converter (FC) concept without extensive re-

³ *** = delivered large series offshore over several years, *= experience is limited to prototype blades or small series only

engineering. At present their largest high speed products are a DFIG of 3.6 MW, a PM of 7 MW and a SC of 5MW.

Further, ABB supplies medium speed PMGs for wind turbines of up to 7MW. This includes the generator supply for Areva's hybrid drive M5000 wind turbine (5MW). Fully integrated options (i.e. combined gearbox and generator) have been supplied up to 5MW.

ABB also provide direct drive permanent magnet generators up to 3MW rating. A number of 2MW generators were provided to Zephyros, which subsequently became Harakosan and which is now owned by STX. Over the last 30 years ABB has supplied around 30.000 generators for wind turbines, with a combined capacity of some 30 GWs.

GE Power Conversion (formerly Converteam)

[<http://www.gepowerconversion.com/>]

In March 2011, General Electric (GE) bought Converteam and in January 2012 it was announced that the Converteam business will be renamed to 'GE Power Conversion'. Prior to 2005, Converteam operated under the name Alstom Power Conversion.

GE Power Conversion have been producing wind generators for more than 10 years, starting with DFIG and more recently medium speed and direct drive PMG. While GE Power Conversion has all the required competence and references to supply DFIGs up to 10MW, their current wind business is now primarily marketed towards PM generators. They delivered their first medium speed PMG for 5 MW wind turbines in 2004, and their first high power (rated 3.7MW) direct drive PMG has been in operation since 2008. GE Power Conversion further provides the direct drive PMG for Alstom's 6MW offshore wind turbine prototypes and China's Envision Energy 3.6MW offshore wind turbine known as GC-1.

GE Power Conversion was contracted as technical lead for the advanced wind turbine testing centre at the UK National Renewable Energy Centre (Narec). They provided equipment including a 15 megawatt, 10 rpm direct drive permanent magnet motor together with an advanced MV7000 variable speed drive unit.

Elin Motoren

[<http://www.elinmotoren.at/en/areas-of-expertise/wind-energy/>]

Elin Motoren are based in Austria and have been supplying electrical motors and generators for a wide range of industrial and energy applications since the early 1900's. Active in the wind industry since 1984, they have supplied generators to main wind turbine OEM's including Vestas, Sinovel, Suzlon, Nordex, and REpower.

For offshore applications Elin Motoren have developed a 3.1MW and a 5.3MW DFIG, both have been in series production since 2009 and 2011 respectively. They state that they also manufacture high speed synchronous generators with either electrical or permanent magnet excitation.

Elin Motoren has capabilities for testing of generators at full direct load up to 6MW.

Emerson – Leroy Somer

[<http://www.emersonindustrial.com/en-EN/Electric-Power-Generation/Industries/Pages/wind-power.aspx>]

Emerson Leroy Somer offer various generator types including PMG and Electrically Excited Synchronous Generators EESG at low, medium and high voltage level. At this moment they have a preference for EESGs due to, in their view, unstable rare earth material prices. Their current wind turbine range is up to 5MW, but they have experience in electric machines of up to 20MW in other industries.

Emerson also has in-house converter design and production.

Ingeteam

[<http://www.ingeteam.com/>]

Ingeteam is a Spanish manufacturer of electrical systems for a wide number of markets, including hydro power and rail traction, besides renewables.

The company has manufacturing facilities in USA, China and Europe. Currently, more than 14,000 wind turbines are fitted with Ingeteam converters and generators, accounting for a power output capacity of more than 22 GW. They have supplied large numbers of DFIG machines to Gamesa and Acciona.

Ingeteam's current generator product range includes the INDAR PMGW series of permanent magnet generators, designed specifically for the wind sector, available in low, medium and high speed versions and covering a power range up to 8MW. The company also provides Squirrel Cage generators up to 8MW rating and DFIG generators up to 6MW.

The xDFM series is a new electric topology comprising an exciter machine (e.g. PMG) mechanically coupled to a doubly fed induction generator. A power converter, isolated from the grid, is electrically connected in between both machines. This technology is marketed by Ingeteam as Ingecon® CleanPower.

Ingeteam are able carry out load tests for wind generators up to 8MW.

Siemens Industry

[<http://www.industry.siemens.com/verticals/global/en/wind-turbine/power-generation/Pages/Default.aspx>]

The Siemens LOHER wind generator product range includes permanent magnet and electrically excited synchronous generators up to 5MW, DFIG generators up to 10MW and squirrel cage induction generators up to 6MW.

In September 2012, Siemens Drive Technologies Division announced the development of a new PMG direct drive generator. The design is characterized by a modular platform which features standardized components, options for either internal or external rotor configurations in combination with outputs of up to 10MW.

The first prototype of the drive has been developed with manufacturer Blaaster Wind Technologies and was installed in Valsneset, Norway in the summer of 2012.

Over 18,000 wind generators have been shipped worldwide.

The Switch

[<http://www.theswitch.com/wind-power/>]

Based in Finland, The Switch offers various permanent magnet generators. They have design ability and some manufacturing capacity; however they rely heavily on manufacturing partners for production as they have limited facilities in house. Since July 2014, Yaskawa Electric Corporation of Japan fully owns The Switch, with “The Switch” remained as a brand name.

The Switch has provided a number of direct drive generator systems. These include 4.25MW units provided to ScanWind (now part of GE) and several 1.5MW generators to Dong Fang Electric Machinery.

FusionDrive is a recent development by The Switch in collaboration with Moventas, which consists of an integrated medium speed PMG with a two-stage planetary gear. Designed for power ratings of 3MW and 7MW, the FusionDrive is reported to offer the lowest drive train weight in the market. The first delivery of a commercial order for FusionDrive™ was announced in April 2012

VEM

[<http://www.vem-group.com/en/system-solutions/renewable-energy.html>]

VEM Sachsenwerk GmbH has supplied generators to DeWind, Repower (Senvion), Nordex, GE, Vensys, amongst others.

VEM’s generator portfolio includes high speed DFIGs up to 6.5MW and synchronous generators (electrically excited, single stage PMG) up to 2.5MW. At present, their largest direct drive PMG is designed for 2.5MW. VEM has testing capability for generators up to 6MW.

Manufacturer	Largest High Speed DFIG (MW)	Largest Medium Speed PMG (MW)	Largest Direct Drive PMG (MW)	Track Record ⁴	Testing Capacity
ABB	3.6	7	3	***	available
GE Power Conversion	-	5	6	**	available
Elin Motoren	5	-	-	**	Available, up to 6MW
Emerson	-	-	-	**	available
Ingeteam	6	8	8	***	Available, up to 8MW
Siemens	10	5	10	***	not known
The Switch	-	7	4	**	not known
VEM	6.5	2.5	2.5	*	Available, up to 6MW

Table 2-3: Summary of generator market participants

⁴ *** = delivered large series offshore over several years, *= experience is limited to prototype blades or small series onl

2.2.4 Bearing suppliers

There are several companies capable of providing main bearings as well as slewing bearings for pitch and yaw systems. The use of bearings is extensive in many industries and therefore the experience and capacity needed for wind turbines exists. However, as the size of the bearings increases, the manufacturing process becomes more complex and the number of companies capable of providing them reduces.

The following companies have a significant market share:

IMO Energy

[http://www.goimo.eu/Wind_energy.1625.0.html]

This company was created in 1988. It has its headquarters and two manufacturing plants in Germany. They do produce main bearings although their best market is slewing bearings for pitch and yaw systems, which they provide to Enercon, GE, Vestas, and Repower.

Liebherr

[<http://www.liebherr.com/en/deu/products/wind-energy/wind-energy.html#!/content=tab-components>]

Liebherr was founded in Germany in 1949. Nowadays the company has expanded to 50 countries targeting eleven different business areas.

They provide ball bearing slewing rings and roller bearing slewing rings for pitch and yaw systems in wind turbines for up to 6m diameters. Their customers include several OEMs such as Enercon, Acciona, Vestas, GE, and Nordex. Liebherr also supports another part of the wind energy business: it supplies cranes including heavy-duty offshore cranes for the assembly of wind turbines.

The large diameter bearings are produced in Biberach an der Riss, Germany, and Monterrey, Mexico, with specifications agreed with customer.

Rothe Erde

[<https://www.thyssenkrupp-rotheerde.com/GB/unternehmen.shtm>]

Rother Erde is a German company founded in 1845. It has its headquarters in Dortmund, Germany as well as a manufacturing plant. A second large manufacturing plant is located in Lippstadt; other subsidiaries are located in Great Britain, France, Italy, Spain, USA, Brazil, India, Japan and China.

Rothe Erde is one of the leading manufacturers of slewing bearings. Their slewing bearings and rings are used in the pitch and yaw systems for wind turbines. They can manufacture bearings up to diameters of 8 m, and on request, rings of around 15 m. In common with Liebherr, Rothe Erde provides bearings for other applications related to the offshore wind energy industry such as harbour cranes, ship deck cranes and other offshore technology. They have applications in underwater turbines and solar energy plants.

The company provides pitch and yaw bearings to several OEMs such as Enercon, Acciona, Vestas, GE, Nordex, Siemens and Gamesa.

SKF

[<http://www.skf.com/group/industry-solutions/wind-energy/index.html?alias=www.skf.com/windenergy>]

Established in 1907, with headquarters in Sweden and the worldwide R&D centre in the Netherlands, SKF has presence in more than 130 countries, and is specialised in 40 different segments. This broadly experienced company provides main bearings for a wide range of OEMs including GE, Vestas, Acciona, Enercon, Gamesa, Nordex, Siemens and Repower. SKF also provides pitch and yaw bearings for Acciona, GE, Repower and Vestas.

Schaeffler

[http://www.schaeffler.de/content.schaeffler.de/en/branches/industry/wind_energy/index.jsp?windpower]

With a history that dates back to 1883 when the FAG brand was officially founded, nowadays the German company Schaeffler has presence in 49 countries with more than 170 locations. In common with SKF, Schaeffler provides main bearings for several OEMs including Alstom, Nordex, Siemens, Sinovel, SHI, Suzlon Group, Vestas and others. They also provide pitch and yaw bearing systems mainly for Alstom.

Timken

[<http://www.timken.com/EN-US/SOLUTIONS/WINDENERGY/Pages/home.aspx>]

Timken was founded as a family company in 1899, based on the invention of the taper roller bearings. Since then the company has grown to become a Fortune 500 company, with headquarters in North Canton, OH.

The company is a leader in taper roller bearings. Most of the products offered to the wind industry are of this type. Timken provides main bearings to Alstom, Siemens and Vestas.

Manufacturer	Largest Bearing Diameter [m]	Main Bearings (MB)	Associated Pitch & Yaw Bearings	Track Record
IMO Energy	5 (MB)	√	√	***
Liebherr	6 (yaw ring)		√	***
Rothe Erde	4 (MB)	√	√	***
SKF	4 (MB)	√	√	***
Schaeffler	4 (MB)	√	√	***
Timken	5 (MB)	√		***

Table 2-4 Summary of main bearing, pitch & yaw bearing market participants

2.3 Services

2.3.1 Testing

Testing of components is usually carried out in-house by the component manufacturer. However there is still the need for testing of the whole turbine (field testing) or the full nacelle to validate integration, performance and reliability. The following paragraphs describe the capabilities of facilities with the capacity to test drive trains, blades, materials or the whole wind turbine.

CENER – The Wind Turbine Test laboratory (LEA)

[<http://www.cener.com/en/wind-energy/wind-turbine-test-laboratory.asp>]

The Wind Turbine Test laboratory (LEA) belongs to the National Renewable Energy Centre (CENER) of Spain. It has the capability of testing components as well as the whole wind turbine. There are five laboratories for component testing: a blade test lab for blades up to 75 m (static and fatigue tests) and for blades up to 100 m (static tests), a powertrain test lab (generator test bench up to 6 MW, nacelle test bench and nacelle assembly bench), a composite materials and processes lab, a wind turbine field test group and finally an experimental wind farm with 6 calibrated locations for turbines of up to 5 MW each and 5 meteorological towers. They offer accredited field tests on power curve, acoustic noise, energy quality and mechanical loads.

Center for Wind Power Drives (CWD)

[<https://www.cwd.rwth-aachen.de/1/home/>;
<http://www.windpower.org/download/2442/Aachen.pdf>]

The Centre for Wind Power (CWD) is part of the Power Generation and Storage Systems (PGS) institute from RWTH Aachen University. The CWD recently inaugurated (March 2015) a 4MW test rig with the Winergy HybridDrive. The centre had previously built a 1 MW test rig as a proof of concept, which tested with the Vestas V52. The CWD does full size nacelle tests and includes condition monitoring testing.

DEWI

[<http://www.dewi.de>; <http://www.reuk.co.uk/Worlds-Largest-Wind-Turbine-Generator.htm>]

Offshore and Certification Center GmbH (DEWI-OCC) was established in 2003 as an approved certification body for onshore and offshore wind turbines. DEWI operates two test sites, one is in Wilhelmshaven, Germany and the other one is located at West Texas AM University, USA.

The Wilhelmshaven site is currently testing ten prototypes of various European manufacturers. It has the capability of testing small and large wind turbines, and has a total capacity of more than 19 MW. The Sevion 5 MW turbine was tested there in 2006.

Additionally to the test site, DEWI provides field and laboratory testing for verification purposes: wind turbine function, safety, structural integrity, power performance, power quality, and acoustic noise emission characteristics.

EWTW

[<https://www.ecn.nl/extranet/ewtw/>]

The Energy research Centre of the Netherlands (ECN) has a wind turbine test site at Wieringermeer (EWTW). It comprises a combination of a wind farm and prototype test location. The wind farm consists of 5 Nordex N80 turbines of 2.5 MW, and there are 6 other locations to test, optimise and certify prototypes. By 2018 it is expected to have an additional 3 prototype testing locations. The installed capacity of the current turbines ranges from 2.3MW to 5MW.

Additionally, ECN is developing a test site near Eemshaven, Groningen to test very large offshore prototypes, expecting the first one to be installed in 2016.

Fraunhofer IWES

[<http://www.windenergie.iwes.fraunhofer.de/en.html>]

German institute founded in 2009 to work on wind energy and energy system technology. This institute has extensive testing and experimental facilities, with state-of-the-art equipment.

Complete blade testing up to 90 meters, including static testing and cycling testing both uniaxial and biaxial; a test centre for support structures (towers and foundations) on a scale of 1:10 and larger; a dynamic nacelle testing laboratory (DyNaLab) equipped with what is claimed to be the world's most comprehensive grid simulator (up to 8 MW capacity); load measurements of wind turbines; offshore test sites to test reliability of sensor systems; measuring techniques for offshore conditions; automated rotor blade manufacturing lab to test the adaptation of materials and procedures to the demands of automated production; oil sensor test stand; test bench for main shafts; rain erosion test bench to test the resistance of rotor blade coating to rain erosion and to investigate solutions; climate chamber for combined loads to simulate actual loads under offshore conditions and evaluate the impact on reliability; and material, component and structural testing.

Hunterston

[<http://sse.com/whatwedo/ourprojectsandassets/renewables/Hunterston/>;
<http://www.artemisip.com/applications/wind-turbines>]

The Hunterston Offshore Wind Test facility started construction in 2013. It is an onshore testing site for offshore wind turbines in UK. The first turbine installed for testing was the SWT-6.0-154; the second turbine was the 7MW Mitsubishi SeaAngel turbine, renamed as the 7 MW Offshore Hydraulic Drive Turbine after Mitsubishi abandoned the commercialisation of the Sea Angel.

The site location replicates offshore conditions, has access to the grid and easy access for component delivery.

KC WMC

[<https://www.wmc.eu/>]

The Knowledge Center WMC started in Delft University of Technology (TUD) as the WMC-Group, testing full-scale rotor blades in 1984. Due to the needed increase in size, in 2003 the centre was moved to Wieringerwerf, NL. The new centre was renamed by TUD and ECN as KC WMC.

The KC WMC is capable of performing blade, material and structural testing of large structures and components. The blade testing includes blade weight and centre of gravity characterisation, modal shape analysis, static, fatigue, post fatigue and torque tests.

LORC

[<http://www.lorc.dk/test-center/lorc-nacelle-testing>]

LORC is a non-profit foundation established in 2009 by commercial companies such as Siemens, Vestas, Dong, Vattenfall, A.P. Moller and Wave Star. Their activities include component & structure and nacelle testing.

The Component & Structure testing facility focuses on mechanical testing such as materials, foundation structures and components; and climatic testing through exposure of structures such as cooling systems, transformers, hydraulic systems, generators, gears, etc. to varying climatic conditions.

The nacelle testing facility is a two test-dock design: one dock for mechanical testing (static and dynamic) and HALT (Highly Accelerated Lifetime Testing); the other dock, the Function Tester, to test the functionalities and performance of the nacelle. The Function Tester has the capability of including the hub allowing the use of the pitch system. Consequently, the original software to be used in the field can be installed in the Function Tester.

NWTC

[<http://www.nrel.gov/wind/facilities.html>]; http://www.nrel.gov/wind/testing_support.html?print]

The National Wind Technology Center (NWTC) at the National Renewable Energy Laboratory (NREL) has the capabilities to support the installation and testing of wind turbines that range in size from 400 W to 5.0 MW. Their capabilities include structural testing, drivetrain testing and field testing.

The NWTC can carry out structural testing of blades, which includes mass and centre of gravity tests, modal characterization, static load cases and fatigue testing; dynamometer testing for drivetrains in the range of 10 kW up to 5 MW; and field tests including turbine structural dynamic characterization and full scale modal testing.

The NWTC is accredited by the American Association of Laboratory Accreditation (A2LA).

ORE Catapult

[<https://ore.catapult.org.uk/testing>]

The Offshore Renewable Energy (ORE) Catapult, formerly NAREC, is the UK's technology innovation and research centre for offshore wind, wave and tidal energy.

They have reliability, design verification and accelerated testing facilities. Their testing capabilities include blade and drivetrain testing, electrical networks, small wind turbines (accredited by UKAS as IEC 17025 test laboratory for testing for less than 200 m² of swept area). Since 2013, they are capable of testing up to 100 m blades. They have a 15 MW drivetrain test facility for offshore wind turbines running Highly Accelerated Lifetime Testing (HALT), complete nacelle or major component testing, power curve assessment, design verification of control system, system performance and endurance, validation testing, etc.

Additionally, ORE plans to have an offshore wind demonstration site (off Blyth). By 2017 ORE aims to have its 99 MW grid connected, offshore demonstration, comprising 15 turbines at 3 different water depths (35m, 45m, 55m).

ORE carried out the testing of the SHI 7 MW turbine.

Østerild (DTU)

[<http://www.vindenergi.dtu.dk/english/About/Oesterild.aspx>]

Test Centre Østerild was established in 2012. It comprises 7 prototype locations that are already taken by industry. The stands allow turbines up to 250m in height. Vestas has three stands, two of them occupied: one with the V164-8, another one with the V126-3.3; Siemens has two, one with the SWT-6.0-154 and the other one with the SWT-4.0-130. The former has been taken down and it is expected to be replaced with a similar turbine by 2015.

The Østerild test site is owned by the Denmark's Technical University (DTU). DTU Wind Energy is at the same time operating two other wind turbine test sites in Denmark: one at DTU Risø Campus, Roskilde and the Høvsøre Test Site for Large Wind Turbines at Lemvig. The latter has 5 stands with the following turbines: V90-2.0, SWT 4.0-130, SWT 3.0-113, and N100-3.3. The missing stand is reserved by LM Wind Power.

SCE&G Energy Innovation Centre

[<http://clemsonenergy.com/>]

Located in North Charleston, SC, USA, the SCE&G has test rig capabilities for up to 15MW turbines. There are two test rigs, one of 7.5 MW capacity and the other one of 15 MW capacity:

7.5 MW test rig: designed to test gearboxes and nacelles for wind turbines up to 7.5 MW.

15 MW test rig: designed to test complete geared and direct-drive wind turbine nacelles up to 15 MW, also large gearboxes and generators.

Additionally, the centre also has a 15 MW Hardware-In-the-Loop (HIL) Grid Simulator, which allows manufacturers to test mechanical and electrical characteristics of their wind turbines in a controlled

environment. The testing includes fault ride-through testing at the multi-megawatt level; and parallel model verification, in which the actual behaviour of the turbine and the detailed dynamic model can be compared.

The centre was designed and built, and it is now operated by Clemson University. More than 90% of the major wind energy companies are represented in the advisory boards, including: Bosch-Rexroth, Gamesa, GE, Nordex, Senvion, Siemens, Timken and Vestas.

Siemens

[\[http://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2013/energy/wind-power/ew201303023.htm&content\[\]=EW&content\[\]=WP\]](http://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2013/energy/wind-power/ew201303023.htm&content[]=EW&content[]=WP)

In 2013 Siemens Energy opened two major Research & Development test facilities for wind turbines in Denmark. One test centre is located in Brande, and it is designed for testing of major components such as generators, main bearings and complete nacelles. The other one is in Aalborg, designed for full scale tests of blades (7 stands). Both testing facilities are capable of performing Highly Accelerated Lifetime Tests (HALT); they are capable of testing the 6 MW direct drive platform, including the 75 m long blades.

TKI Wind op Zee

[\[http://www.tki-windopzee.nl/\]](http://www.tki-windopzee.nl/)

TKI Wind op Zee (Top consortium for Knowledge and Innovation Offshore Wind) is planning an offshore testing and demonstration site, the Leegwater project, where newly developed technologies can be tested.

WINDTEST Kaiser-Wilhelm-Koog (WTK)

[\[https://www.dnvgl.com/energy/generation/index.html\];](https://www.dnvgl.com/energy/generation/index.html)
[http://217.41.48.40/norse/index.php/partners/gl-garrad-hassan-germany\]](http://217.41.48.40/norse/index.php/partners/gl-garrad-hassan-germany)

WINDTEST Kaiser-Wilhelm-Koog (WTK) is a testing laboratory for wind turbines situated in Kaiser-Wilhelm-Koog in the north of Germany, approximately 100 km north-east of Hamburg. Since 1989, WINDTEST is carrying out measurements on wind turbines and in wind farms. The range of measurements encloses all kind of wind potential measurements, power performance measurements, load measurements, noise measurements and power quality measurements, according to common guidelines such as IEC- or MEASNET-guidelines.

WTTC

[\[http://www.masscec.com/wttc\]](http://www.masscec.com/wttc)

The Wind Technology Testing Centre (WTTC) in Massachusetts, USA, at the Massachusetts Clean Energy Centre (MassCEC) opened in 2011 a Large Blade Testing Facility with capacity to test blades up to 90m. The tests include a full suite of static and fatigue tests, blade material, dual axis static or

fatigue testing, lightning protection testing (pending design), prototype development and blade repair capabilities, etc.

WRD (Wobben Research & Development)

[<http://www.enercon.de/en-en/1816.htm>]

Enercon's test and verification site for blades, generators, full nacelles, components and materials, is located in Aurich, Germany. It has a hall for nacelle and generator testing and a hall for testing blades of up to 70 m length.

Janneby

Wind turbine prototype test field in the North of Germany. The test field is designed for the assessment of new wind turbine prototypes, a crucial part of being able to obtain certification for a new product. The site comprises eight test beds and meets IEC Class II wind condition classification. The average annual wind speed is 7.1m/s at 100 meters high. The testing phase can run up to five years, for turbines of up to 150m in total height.

3 Dutch Capability

Table 3-1 provides an overview of the various organisations with a strong footprint in the Netherlands, alongside a high level assessment of the current level of competitiveness in the market segments. Note the table does not aim to be complete; only the wind turbine system and its main components are considered, not secondary components, auxiliary components or aspects at sub-component level.

Sector	Market leaders	Active NL presence in offshore	Potential to enter market	Competitiveness
Turbine design & technology	Siemens Wind, MHI Vestas,	DNV GL, Mecal, ECN		Average
Turbine supply	Siemens Wind, MHI Vestas	XEMC Darwind, 2B-Energy, Siemens (small design office)	Lagerwey, EWT	Weak
Blade design and supply	Tier 1 OEMs, LM Wind Power	LM Wind Power, DSM	WE4C, TRES4, Pontis, Suzlon	Average
Gearbox supply	Winergy, ZF	-	GCI, VDI (Bosch)	Weak
Generator supply	Tier 1 OEMs, ABB	-		Weak
Main bearing supply	Schaeffler, SKF, Timken	SKF		Average
Testing prototypes	RISOE-DTU, Hunterston, WTK	EWTW (ECN)		Average
Testing drive trains	Tier 1 OEMs, LORC, NWTC, ORE Catapult, CENER, CWD	-		Weak
Testing blades	Tier 1 OEMs, Fraunhofer IWES, ORE Catapult, CENER	KC-WMC		Average
Assembly	Tier 1 OEMs			Weak
Logistics	Tier 1 OEMs			Weak
R&D: academics & institutes	DTU, NREL, ForWind, DUWIND, ECN	DUWIND, ECN,		Strong

Disruptive - airborne	Google (Makani), Ampyx power	Ampyx power	Strong
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Table 3-1 Existing offshore wind turbine market: Dutch competitiveness versus leaders

To summarize Table 3-1, The Netherlands has relatively little capability within the wind turbine and component value chain, except for research and development.

In particular the lack of a major WTG OEM is a major disadvantage for the Netherlands given the central role they play in wind turbine related economic and technology activities. Whilst not at systems level, The Netherlands does have a few strong actors, but then on the components level, notably the key components of blades and bearings with LM and SKF, respectively. In the wind technology services market, The Netherlands has a reasonable position in blade and prototype testing and an excellent position in R&D, the latter with two of the leading parties; DUWIND and ECN. One of the leading start-ups in the potentially disruptive technology of airborne wind is Dutch: Ampyx Power.

4 Innovations in Turbine Technology

4.1 Innovation driver: LCOE reduction

The overarching motivation for turbine technology innovation lays in its promise to lower the Levelized Cost of Energy LCOE for offshore wind.

Lowering LCOE is a big theme throughout the offshore wind value chain and across all of the major offshore wind markets, as is e.g. reflected in a recent DNV GL summary of the dozens of current initiatives /3.

To appreciate the drivers in reducing LCOE, first the various contributors to the LCOE of offshore wind and their relative size are exemplified in Figure 4-1, taken from the Offshore wind cost reduction pathways study issued by the Crown Estate /4. Capital expenditure accounts for about 60% of LCOE, main contributors being turbine and support structure capital, installation capital and other capital, e.g. project development and contingency. Operational costs account for about 15% and a similar contribution comes from the transmission charge; a typical UK arrangement where the developer develops and builds its offshore transmission link only to sell to a 3rd party (the Offshore Transmission Owner) who will operate the transmission link for an annual fee.

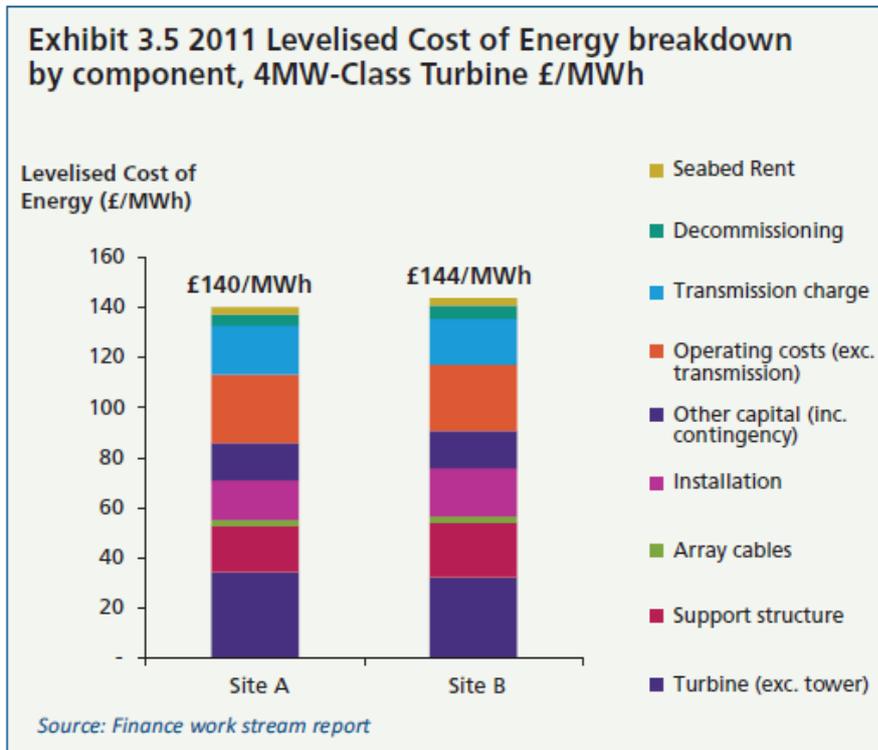


Figure 4-1 typical LCOE breakdown for a UK offshore wind farm. Source: /4

Departing from this 2011 LCOE-base, a tentative quantification of LCOE-reduction opportunities up to 2020 is also given in the Crown Estate cost reduction study /4, see Figure 4-2. Turbine related opportunities are anticipated to be responsible for about half of the total LCOE-reduction over these 9 years up to 2020. This LCOE reduction of about 40% is echoed in the TKI Wind op Zee Roadmap 2015 – 2020/7 that furthermore yields a similar breakdown of the 40% into the various contributing elements.

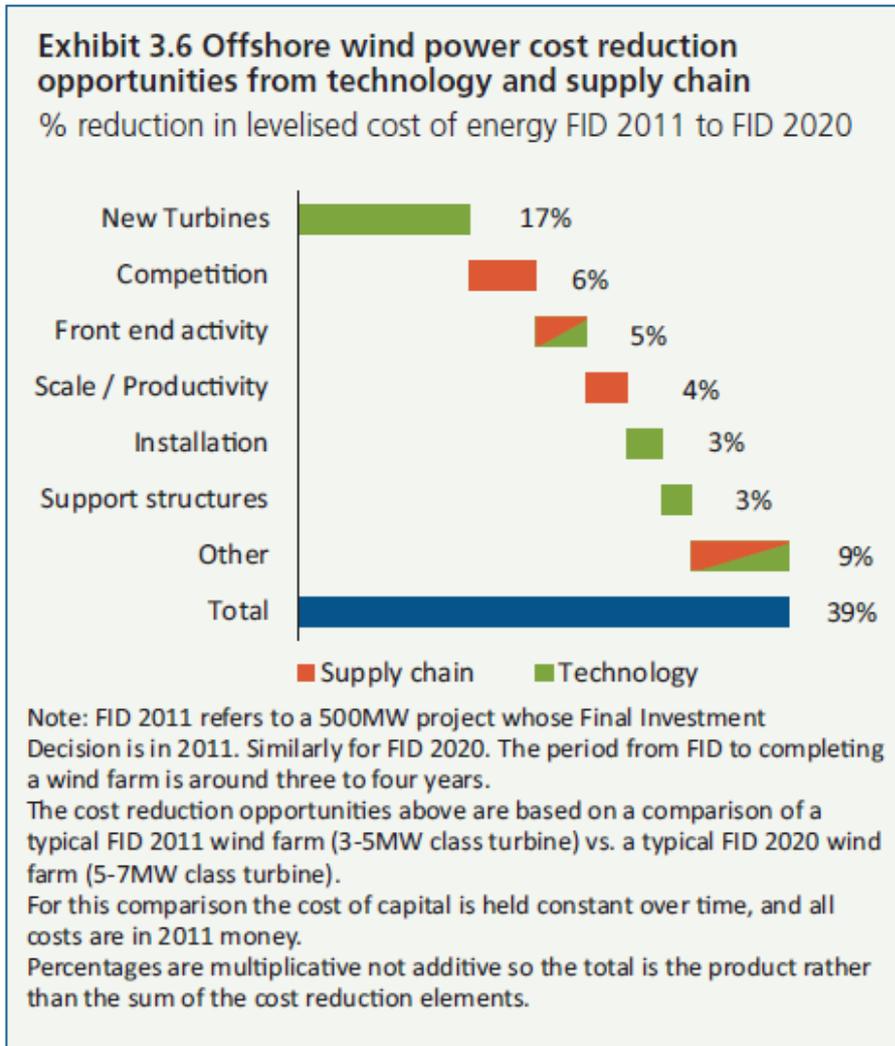


Figure 4-2 LCOE-reduction opportunities. Source: /4

For the current study, the horizon of the technology outlook is 2030. These extra 10 years compared to the 2020 timescale of the DNV GL manifesto for cost reduction /3, the Crown Estate offshore wind cost reduction pathways study /4 and the TKI roadmap /7 lead to an increased uncertainty over the estimated LCOE-reduction from wind turbine technology innovations. However, the predicted 2030 LCOE-reduction would be larger than that foreseen for 2020;

- The currently identified key technologies have 10 more years to mature and thus to deliver on and surpass their entitled potential for 2020
- Currently infant or non-existent technologies – with associated marginal or no contribution to 2020 LCOE-reduction – could bring in substantial LCOE-reduction by 2030

The total foreseen LCOE-reduction from turbine technology improvements is not dominated by a single big hitter. Instead, it's a combination of several items, as illustrated by Table 4-1 on the top 12

innovations in turbine technology. This is based on the Crown Estate’s Cost Reduction Pathways Project, supplemented with additional DNV GL judgement and modelling.

Innovation	Cost Reduction potential
Industrialization	5-10%
Increase in turbine rating	5-10% +
Improved blade design & manufacture	2-5%
Advanced control	2-5%
Drive train concept	2-5%
Optimised Rotor diameter	0-2%
Integrated design	0-2%
Condition based maintenance	0-2%
Turbine logistics and installation	0-2%

Table 4-1 estimated LCOE-reduction opportunity for wind turbine technology

4.2 Industrialization

Further industrialization of the wind turbine supply is identified as a key enabler to lowering the LCOE for offshore wind. Certain production volumes are needed for industrialization to bring in LCOE-reduction. An intelligent means of boosting production volumes for a given component is to employ a product platform strategy; rather than designing, manufacturing and operating each turbine type in isolation, a platform strategy aims to share methods, components, procedures etcetera between various products in the platform. This model has seen successfully applied in the automotive industry.

Key advantages of industrialisation and the associated product platform strategy are:

- Production of higher volume, similar, standardized, modular components for different wind turbine models
- Lower risk
- Subsequent faster time to market for a new turbine model
- Lower component manufacturing & assembly cost
- Operational advantages: cheaper staff training, logistics, installation, O&M
- Shared innovation across the product platform

All of these work to reduce the LCOE.

Within the current offshore market, the wind turbine portfolios of Siemens and Vestas include clear examples of this industrialization.

4.3 Increases in turbine rating and rotor diameter

Increasing turbine size, i.e. rating and rotor diameter, is a key LCOE-reduction opportunity. This is a main driver behind the rapid upscaling of turbine technology over the recent years, see Figure 4-3.

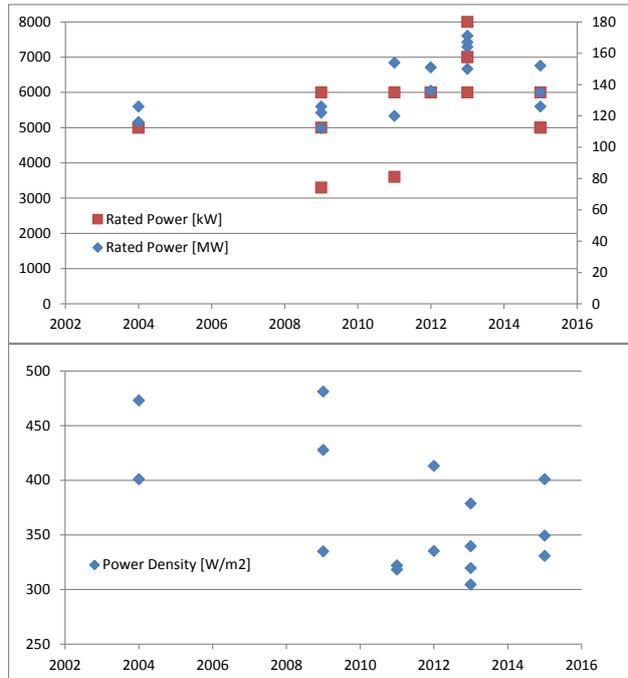


Figure 4-3 Historic growth of turbines

Upscaling of wind turbines obviously results in higher capital cost for the wind turbine. Even more so, basic physical and engineering principles lead to an increased wind turbine capital cost per MW-installed. Hence, for a farm of given MW-size, wind turbine capital cost will increase. Other mechanisms thus drive the LCOE-reduction with larger turbines. For a given farm size, with larger turbines:

- The farm energy yield increases – a small effect when turbine power density is unchanged
- The capital cost for the substructures reduces
- The farm operational cost reduces

Given these opposing cost and yield trends with turbine size, concept engineering models can find an optimum turbine size with minimum LCOE, see e.g. Figure 4-4. Note this optimum size depends on farm specifics and on general market conditions. Further, technology innovations and supply chain developments generally push the LCOE-minimum both down (lower LCOE) but also to the right (bigger turbines) in the graph below. Together with upscaling of the turbine the power density of the rotor, installed rated power per rotor area, has been decreasing.

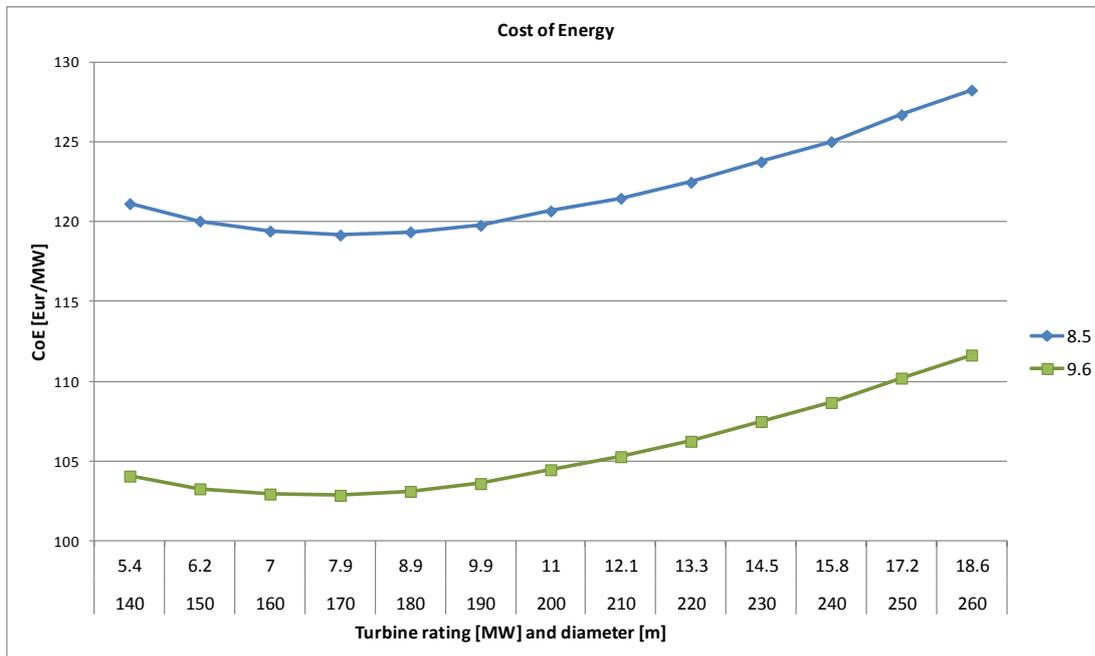


Figure 4-4 example LCOE trend for an offshore farm at two Annual Mean Wind Speeds

As the sector moves towards the next generation of even larger wind turbines, upscaling becomes a concern across many structural components. Two areas are particularly problematic: firstly blades (covered in Section 4.4) and secondly, the main bearing.

4.3.1 Bearings

The main bearing is problematic because for the latest, cutting edge turbines (~6MW) the bearing is around 3.5m in diameter which is on the edge of what is possible to manufacture today, with only two companies in Europe able to do this (SKF and Schaffler). Going forward, bigger turbines would likely need bigger main bearings. This takes the bearing requirements for offshore wind beyond that which is required in other sectors and poses a number of challenges in terms of materials, machining, process and logistics. Bearing manufacturers will be faced with having to spend a significant amount of money investing in new manufacturing facilities with the sole purpose of delivering to the offshore wind market, increasing investment risk.

4.3.2 Structural components

At present, all structural components other than the blades are made from steel. The manufacturing techniques include casting and forging, e.g. for hubs, mainframes (both cast) and shafts (cast or forged).

The high design loads for these large offshore turbines drive towards large and heavy designs of these steel structural components. It is foreseen that the current supply chain capability will be challenged to provide these very large and heavy components. A hub design for a future large offshore turbine might e.g. be seriously constrained by the maximum casting dimensions allowed.

Investing in larger – and more expensive – casting facilities will be a “brute force” way out of this constraint. However, technology innovations may offer more economic solutions, e.g. other manufacturing & assembly methods for these steel components or moving to composite materials.

4.4 Blade design and manufacture

The offshore wind sector has seen rapid upscaling of blades, with the largest blade installed to date (83.5m) unthinkable a few years ago. As mentioned in Section 4.3, a bigger rotor generally results in a more expensive turbine, but still, LCOE could be reduced with larger machines. In this context, it can readily be understood that mitigation of the cost penalty when upscaling to large rotor diameters would benefit further LCOE-reduction.

The technology to enable cost-efficient large rotors includes the area of wind turbine controls, to be discussed in Section 4.5. Focussing on the blade, these technology areas are instrumental:

- Aerodynamics:
 - o tailored airfoil families for large offshore blades
 - o passive aerodynamic devices
 - o active aerodynamics devices (known as active flow control, smart blades)
- Materials & manufacturing:
 - o Improved materials, concerning strength, stiffness, cost, HSE
 - o Modular blades
 - o Improved coatings – including protection against increased tip speeds
- Design:
 - o Advanced load alleviation technology, e.g. flap-twist coupling
 - o Improved methods & tools, e.g. to reduce uncertainty in aero-elastic instability prediction and to optimize blade design from system level perspective

Due to the multi-disciplinary nature of blade engineering, innovation in any of the 3 areas mentioned above (aerodynamics, materials & manufacturing, design) is expected to impact on the other 2.

4.5 Control systems and condition monitoring

Despite significant focus and improvement over the past few years, there remains significant potential to increase the sophistication of control systems and condition monitoring systems for offshore wind turbines. Although often considered separately, control systems and condition monitoring systems both have much to gain from closer integration of sensors and, more significantly, their respective functional capabilities.

Looking forward, DNV GL identifies a number of trends in this area:

1. Further advancement of control at the wind turbine level, including the interaction with condition monitoring and SCADA systems. Two paths can be distinguished; as part of turbine design, controls improvements yield a reduction in design loads that is often used to grow the turbine (rating, rotor), thus benefitting from larger yield. When upgrading the controls during the operational life of a turbine, e.g. the lifetime could be extended, the yield could be increased or the operational cost reduced, thereby adding value to an existing project.

2. Increased sophistication of wind farm wide control systems to co-ordinate and exploit the capabilities latent in the control systems of individual turbines. This need not focus on highly complex computational fluid dynamic models but instead could consider lower hanging fruit through the use of simplistic wake representations augmented with run-time information from turbine local control & monitoring systems to help improve performance, O&M planning and to enhanced grid integration services (fault tolerance, demand balancing and short term frequency support) whilst maintaining structural loads within the design envelope. Furthermore we expect to see inferred structural loading and other asset life predictors play a more significant role in operator's short term local decision making on wind farm rating, service planning and ancillary service provision.
3. Extension of condition monitoring systems to become more offshore wind specific and much more integrated. For instance, to date most of the condition monitoring has focused on the mechanical transmission elements, but this needs to be expanded to include interactions with the blades, electrical elements and broader environmental affects e.g. turbulence, wave loading etc. for which the control system is able to provide key response indicators. A big challenge will be in understanding the interaction between all these different elements. For instance, is a variation from the expected behaviour of the wind turbine due to an impending failure, natural environmental conditions, network behaviour or inappropriate control action.
4. Greater use of this data within operational planning. Developers are starting to use condition monitoring data to plan maintenance but it is relatively immature. At the same time, there are various academic studies considering more sophisticated ways of planning (including the use of artificial intelligence) but this to date has not really been trialled on a real world wind farm.

4.6 Drive train concept

The offshore wind sector has developed a range of drive train concepts next to the standard high speed generator solutions (Siemens G4 platform: squirrel cage, Senvion: Doubly Fed Induction Generator DFIG) including the Siemens 6MW-154 Direct Drive DD Permanent Magnet Generator PMG, the MHI Vestas 8MW-164 medium speed PMG and the MHI Vestas SeaAngel 7MW – Hydraulic drive. Hence, rather than converging towards a winning drive train concept, the drive train landscape is highly diverged for offshore (and equally so for onshore) wind. This observation correlates well with DNV GL engineering-based LCOE modelling of various drive train concepts, where modest LCOE-differences are found. In short, the crux to a successful drive train concept seems to be not the concept itself, but the execution.

A mix of approaches is expected to be used for the foreseeable future. This mix may even grow beyond its current constituents mentioned above, e.g. if superconducting drive train technology matures. The first embodiments of this latter concept are foreseen to be DD generator with “high temperature” superconducting windings in the generator rotor and a classical generator stator.

4.7 Integrated design of turbine and support structure

To date the offshore wind turbine and the foundation have been designed separately, with relatively little data passing between the turbine OEM and the support structure designer and with wind and wave loading considered separately. As a result, the support structure is often over-specified,

increasing cost. Work undertaken by DNV GL suggests that integrated design brings in substantial LCOE-reductions /6. This comes in two distinct steps; the first would be to use a tool capable of capturing the interactions between turbine and support structure. The second is to optimize the combined turbine-support structure design. With the example case studied in this project FORCE /6, LCOE-gains of 2.0% and of another 5.2% were found for steps one and two, respectively, where the second step was materialized by relaxing the support structure frequency constraint.

The wind industry has started to pick this up; 2B Energy has taken an integrated design approach, designing an integrated lattice tower and foundation structure for their 2B6 prototype. Areva and STX have also announced collaboration on an integrated jacket structure, while the Carbon Trust recently launched a project on integrated design through the Offshore Wind Accelerator.

4.8 Logistics and assembly

As wind turbines have increased in size, assembly facilities have had to move to coastal locations. This makes logistics in many ways easier than onshore wind, with major parts such as blades coming in on vessels.

Within assembly lines, OEMs have been seeking to move towards serial production methods, with Siemens expecting significant manufacturing savings from a new factory that will be built in Hull, UK.

In terms of innovations, when assembling wind turbines, OEMs have also undertaken work to reduce the amount of commissioning time taken offshore (an often overlooked element of the construction stage), by pre-commissioning as much as they can onshore. Various ideas have been put forward for facilitating full commissioning onshore through whole turbine installation, but interest in this concept has declined as the wind turbines have increased in size. One potential option to allow full commissioning onshore would be to fully pre-assemble and commission the turbine onshore, breaking the tower into two and then transporting and installing the nacelle and top half of the tower and separately the bottom half of the tower. This would keep the blades out of the water and should optimise the use of the offshore vessel.

4.9 Disruptive

The technology innovations discussed thus far can all be categorized as incremental improvements to the matured wind turbine system; a horizontal axis rotor with 3 (or 2) blades that is fixed to a support structure standing on the seabed. This category does not apply to all ongoing and foreseen offshore wind technology development though; some can in fact be considered as disruptive innovations. By definition, some of the future innovations in this category cannot really be foreseen at present. To briefly summarize current work on disruptive innovations:

Floating wind:

The availability of floating substructures would open up the large, untapped market of windy, deep offshore locations near populous areas, such as the locations in the Mediterranean. Floating may not play a dominant role in the North Sea though, as this area may be too shallow for floating to be cheaper than fixed bed structures. DNV GL estimates the tipping point between fixed bed and floating support structures to be at around 50m water depth.

The innovations enabling floating wind are centred around the floater technology and integrated design of turbine and floater. Hence some impact on turbine design specifications is foreseen.

Vertical Axis Wind Turbine VAWT:

With a VAWT, the undisturbed wind is nearly perpendicular to the rotor axis of rotation as opposed to a horizontal axis wind turbine HAWT where these vectors are nearly aligned. The typical VAWT suffers from two fundamental physical drawbacks; compared to a conventional HAWT, its aerodynamic efficiency and optimum tip speed ratio are substantially lower. As a result, the typical VAWTs is a large, heavy and high torque machine with poorer economics. Given this fundamental drawback, DNV GL does not expect a breakthrough innovation that reduces the LCOE of VAWTs to a level substantially below that of HAWTs. That includes floating VAWTs, as their size and associated centre of gravity are such that possible savings in the floater would be too small to reverse their economic disadvantage over HAWTs.

Hence DNV GL does not predict a bright future for large offshore VAWTs.

Airborne wind:

Similar to floating, airborne wind energy, also referred to as high altitude wind energy, would open up a new wind market. This time, the resource would be strong winds at altitudes of a few hundred meters and up. The energy potential hereof is substantial and relatively evenly spread across the globe. The airborne wind industry is in a pre-commercial phase of concept development, with several concepts developed by various parties. The most promising and possibly most mature concept to harvest this wind resource is through using tethered, cross-wind, kites or gliders. Such concepts could be seen to challenge the LCOE-levels of conventional wind turbines, as their efficient power production – conceptually similar to a horizontal axis wind turbine – is combined with a lean support structure. In contrast to a conventional wind turbine that has to survive in wind speeds above cut-out, e.g. the 50 year storm, the kite (or glider) would be brought to the ground and sit it out. Whilst further concept field tests and prototyping of the first commercial products would probably be most effective on land, due to accessibility, the ultimate location for large-scale commercial airborne wind energy farms might well be offshore, as such farms will have a low energy density (kWhr/km²) and thus will need large areas. Conventional wind turbines had similar reasons to go offshore.

5 R&D programmes and the innovation process

5.1 The current situation

5.1.1 The international context

Wind technology innovation is supported in several of the key wind markets. A brief review of the support mechanisms in two of these markets, the United Kingdom and Denmark, provides a valuable reference for the TKI programme.

The United Kingdom

Historically, government support of wind R&D focussed on technology development. This technology push was not matched by a market pull, since a domestic wind market was lacking and selling technology overseas was challenging. Therefore, the effectiveness of the support schemes was low, even though interesting spin-off has occurred; e.g. Garrad Hassan that emerged from the Wind Energy Group, a turbine OEM that developed interesting technology but lacked commercial success.

At present, the UK lacks turbine OEMs in offshore wind, whilst a significant offshore wind market has been built with the help of government support. Given the sizeable market, the current focus is on building a local supply chain, rather than turbine OEMs.

Several support schemes are available. The main ones are:

- The Innovate UK (former: Technology Strategy Board TSB) energy catalyst scheme. Any UK company can apply and if successful, a grant will be provided covering a percentage of the total cost. The IP is owned by the contractor.
- The offshore renewable energy ORE catapult: they serve as a centre of excellence, non for profit organisation with the function to build bridges and link companies. ORE Catapult works with the contractor and tends to want to own the IP.
- The Carbon Thrust (CT) offshore wind accelerator: a consortium of major offshore wind developers that identifies key barriers and contracts organizations to help break them. The organisation is non for profit and received private investment next to limited government support.
- Engineering & physical science research council (EPSRC) for wind: they fund university research. Projects often are isolated with benefits not effectively shared with industry, also since industrial partners act as observers, rather than active participants driving the content. The EPSRC also funds doctoral training centres for wind energy (Strathclyde) and marine (Edinburgh, Exeter).
- Energy Technology Institute ETI: A public-private cooperation between energy companies (e.g. Rolls Royce, Caterpillar, Shell etc) and government (50-50). IP-ownership is an issue and the success rate in offshore wind is limited.

DNV GL observes that the overarching coordination between all these schemes could be improved, e.g. through the development of a strategic roadmap. Hereto, the government has initiated a Cost Reduction Task Force for offshore wind that has resulted in joint coordination efforts by the Offshore Wind programme board and the Offshore Wind Industry Council of all offshore wind activities in the UK, with innovation one element.

Denmark

The Danish model has, since its beginning, tried to stimulate both a market pull and a technology/product push. The Danes refer to this as the triple helix. The industry thus works with government ministries and the Danish R&D institutes.

The Energy Technology Development and Demonstration Program (EUDP) is the main funding body for development and demonstration of new (offshore) wind technology. Overall coordination of the programme is carried out by DTU-RISOE. The issue of IP ownership is addressed per individual project. Further, direct competitors, e.g. Vestas and Siemens, sometimes participate in the same project, in case the topic is generic.

DNV GL observes that the consistent government support for both market and product in Denmark is one of the key factors in the global success of Danish wind industry.

5.1.2 The TKI

New economic policies initiated in 2011 have resulted in the identification of nine sectors as “Topsector”, including energy. Within the Topsector Energy, seven Topconsortia voor Kennis en Innovatie (TKI) have been established, including wind op zee (WoZ).

The TKI-WoZ aims to 1) achieve a 40% cost reduction in 2020 versus the 2010 baseline, 2) strengthen the economic activity in offshore wind in the Netherlands and 3) support the Dutch offshore wind sector in the international markets. To achieve these aims, the TKI plays on five levels; component, wind farm, sector and system.

Focussing on the component level, an R&D program has been setup with five themes; support structure, wind power station (including the turbine), electrical, transport – installation – logistics and O&M. The R&D program works with tenders to provide the support grants. A total of five tender rounds have been organized, with limited success. DNV GL observes that restrictive tender rules are in part to blame, e.g. the fact that unused funds cannot be rolled through to the next tender round.

5.2 Key lessons from innovation support in offshore wind

This chapter considers lessons learnt in over a decade of innovation funding for offshore wind seeking to draw out specific recommendations for TKI funding in turbines and turbine components.

Lesson 1 – Understand broader barriers to innovation

Funding is only one element of bringing forward innovation. Often other non-financial barriers may be as important, for instance, ability to test a new product, access to the end customer, help pre-qualifying for large suppliers. Understanding these broader barriers are critical, needing a holistic perspective.

For instance, when reserving demonstration bays for the prototyping of new turbines a whole range of issues will need to be addressed. These include procurement rules –can major utilities contract a turbine which has been effectively pre-selected by the tender process? Who pays for the increase in cost of having to operate two different turbines on the same site? How is the grid connection dealt with? What if the prototype turbine trips, bringing the rest of the wind farm down? All of these kinds of issues will need to be addressed.

Lesson 2 – Market pull is a crucial element

The early days of wind power highlight the importance of market demand for innovation with Denmark pulling ahead of the UK because of a strong local market demand. Within NL the “Energie akkoord” provides significant impetus and clarity of pipeline going forward. TKI should consider how this market pull could best be used to stimulate innovation.

Lesson 3 Maximise bang from the buck through grouping of initiatives

Inevitably there will always be greater demand for innovation funding than supply which means a need for rationing and seeking to maximise efficiencies. One means of doing this is to identify synergies between different types of innovations and provide support that helps all of them. For instance, the Netherlands has strong capability across early stage testing and demonstration sites across different organisations. To help provide a more complete picture, TKI could seek to build partnerships between these companies therefore providing OEMs with a more complete picture. Similarly if TKI is reserving turbine bays then consideration needs to be given as to what else could be usefully provided on the back of this. For instance, the industry is becoming increasingly interested in integrated design; the tender could be designed to help incentivise collection of loads data that could help Dutch foundation manufacturers design more integrated support structures.

Lesson 4 – Ensure coordination

There is a huge amount of innovation ongoing across the sector and it will be important that the Netherlands understands what else is going on in this area across Europe and focuses on those areas where there is a natural competitive advantage, playing to the existing strengths.

Lesson 5 – Ensure buy in from key industry players

The UK has worked hard in recent years to ensure that industry initiatives have the buy in of senior industry and Government stakeholders. This is primarily through the Offshore Wind Programme Board and Offshore Wind Industry Council which are chaired by Ministers and CEO’s of the leading developers and supply chain actors. Through this, it has been possible to get top down buy in to initiatives such as the Cost Reduction Monitoring Framework, providing access to data which would otherwise have been almost impossible to obtain going bottom up.

Within the Netherlands, it would appear sensible to engage with the leading OEMs and key developers on the initiatives proposed in this report to ensure that they agree with the findings and would be keen to support them going forward. Ideally this would be done at a senior level and recorded to help ensure compliance at a later date

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