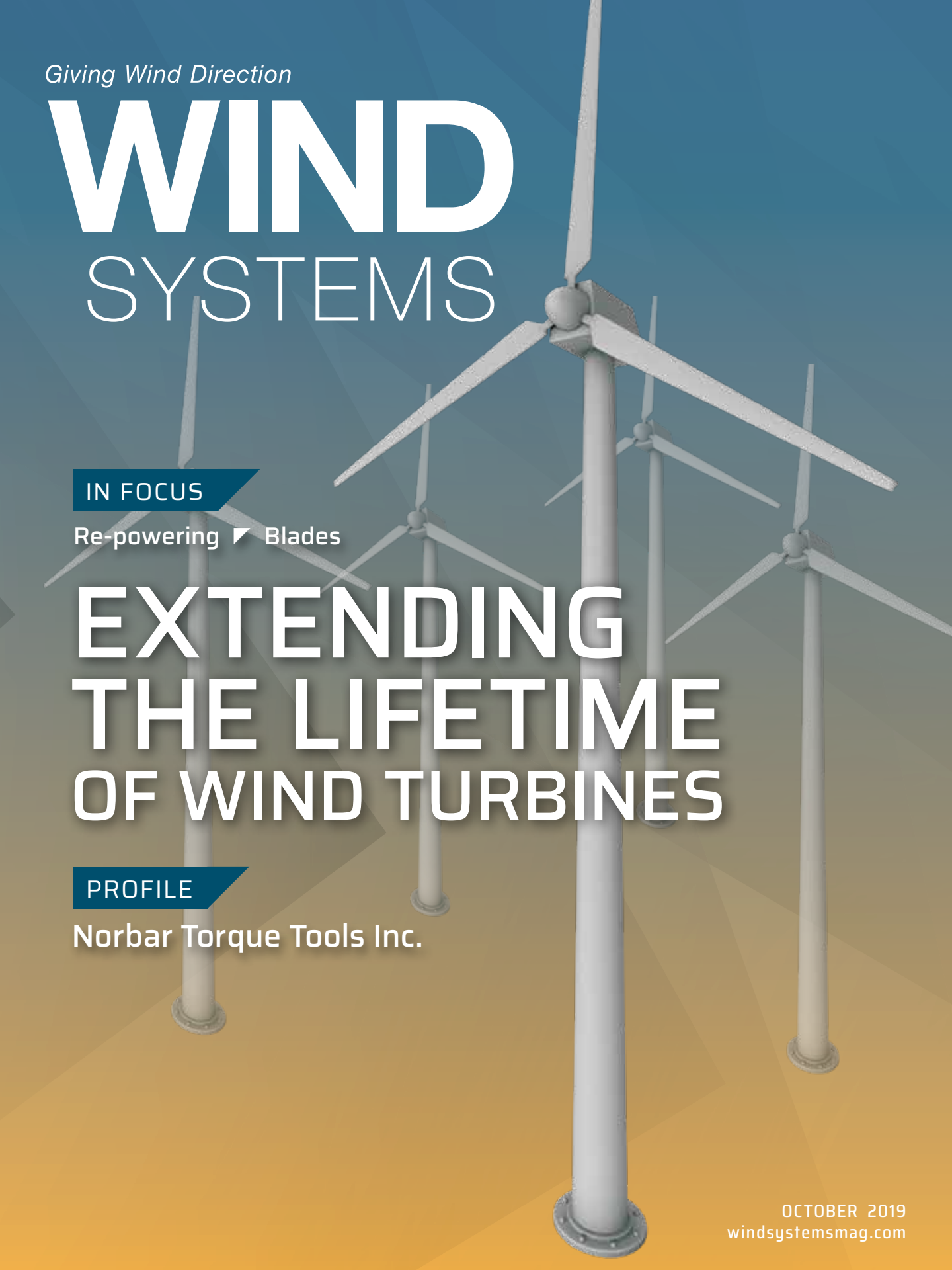
Giving Wind Direction

WIND SYSTEMS



IN FOCUS

Re-powering ◤ Blades

EXTENDING THE LIFETIME OF WIND TURBINES

PROFILE

Norbar Torque Tools Inc.

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Wind Project O&M and Safety Conference
February 26 – 27, 2020 | San Diego, CA

Wind Project Siting and Environmental Compliance Conference
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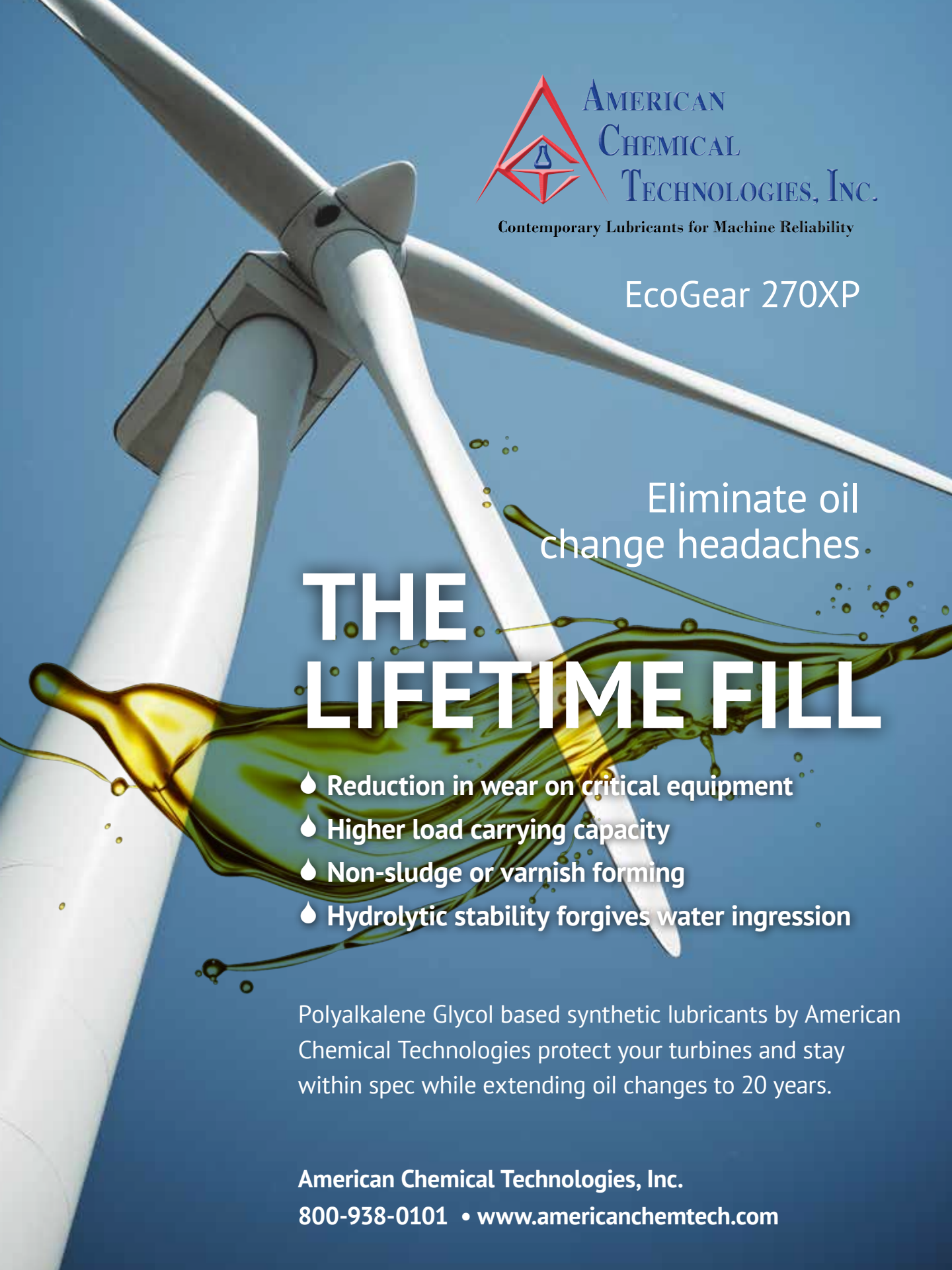
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FUNDAMENTALS OF WIND TURBINES

Global capacity has grown continuously since 2001, including a 9-percent increase in 2018.

TAILWINDS

THE BUSINESS OF WIND

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Giving Wind Direction
WIND SYSTEMS

Innovation is a key to wind's success

One of my favorite things about wind energy is the constant innovation that surrounds and pushes the industry to new heights — sometimes, quite literally.

That's why I always enjoy the issues of *Wind Systems* that take a closer look into technological strides that keep wind growing across the U.S. and the world.

The October issue shines a spotlight on two subjects that power this innovative buzz: re-powering and the advances in turbine blades themselves.

Blades keep getting bigger and bigger. Siemens Gamesa continues to push the boundaries of that fact by building the world's largest turbine blade test stand in Denmark. The inaugural test will be on the company's massive 94-meter-long blades for its SG 10.0-193 DD model turbine.

Let's put that number into some real-world perspective: 94 meters is more than 308 feet. Next time you're at an (American) football game and watching the players scramble across the field, realize that just one of these blades would stretch from end zone to end zone. There's a word for that: Wow!

Blades are the literal starting point of transforming wind into electricity, which is why so much emphasis is placed on ensuring they continue to be produced with the upmost optimization.

In our inFocus section, Jacob Goldman, cofounder and CTO of Ahead Wind Inc., shares his insights about how additive manufacturing can be used to create blade molds, producing alternatives to composite-molded or machined parts.

And as turbines approach their end-of-life, the concept of re-powering is a big part of the wind industry as the countdown clock on the PTC ticks closer to zero.

In an article from TÜV SÜD's Christian Schumacher and Florian Weber, the results of lifetime extension assessments conducted by the company indicate that most turbines can continue to operate in a safe and economically viable way for several years beyond their defined service lives.

In this month's Crosswinds article, Jane Marie Andrew and the Society of Tribologists and Lubrication Engineers take a deep dive into the science of wind and the physics that turn wind into energy.

The wind industry, just like the wind itself, is always changing. *Wind Systems*' October issue is proud to point out just a few of these important aspects of just what keeps the industry moving and growing.

Enjoy the issue, and thanks for reading!

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Giving Wind Direction
WIND SYSTEMS

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Conference chairs announced for Denver's CLEANPOWER 2020

From AWEA

AWEA recently announced conference chairs for CLEANPOWER 2020 (CP 2020), the new pan-renewable conference and exhibition hub for the U.S. energy industry launching next year. Chris Brown, president of Vestas' sales and service division in the U.S. and Canada, and Teresa Mogensen, senior vice president of Energy Supply at Xcel Energy, will provide vision and leadership defining CP 2020 conference program objectives, including the selection of session topics and speakers.

Brown is an energy industry leader with decades of experience running electric utility and independent power operations. He also serves on the Vestas Wind Systems executive committee as group senior vice president for the world's largest provider of wind turbines. Mogensen is responsible for an 18,000-MW power generation fleet that supplies electric power for 3.5 million customers in eight states. Xcel Energy is committed to leading the clean energy transition and is adding significant new wind, solar, and energy storage assets to its diverse energy mix.

At the WINDPOWER 2019 Welcome General Session, AWEA CEO Tom Kiernan announced the creation of CLEANPOWER as the new exhibition hub that will bring together the utility-scale wind power, solar power, and energy storage industries when it launches in Denver in June 2020. By incorporating these technologies into a single exhibition hub, CLEANPOWER will create efficiencies for exhibitors and attendees with multi-technology business models. Pure-play businesses will benefit from increased show traffic and opportunities to build beneficial partnerships across the cleantech industry.

Make plans to attend CLEANPOWER 2020, June 1-4, 2020, at the Colorado Convention Center in Denver, Colorado. Registration opens this fall. For details on registration, speakers, exhibits and other developments, go to www.cleanpowerexpo.org.

AWEA AMERICAN WIND ENERGY ASSOCIATION

The American Wind Energy Association (AWEA) is the premier national trade association that represents the interests of America's wind energy industry. For more information, go to www.awea.org

DIRECTION

THE FUTURE OF WIND

The offerings provided by Semco Maritime may include studies related to how to transmit offshore wind power to the onshore power grids factoring in the balance between project capital versus operational expenditures and asset availability. (Courtesy: Semco Maritime)

Semco Maritime adds new business area for offshore wind

Semco Maritime plans to leverage two decades of offshore wind project experience into a new business area focusing on the concept and feasibility phases of offshore wind projects.

Semco Maritime has a significant footprint in the offshore wind market, providing EPC solutions for offshore high-voltage substations (in cooperation with long-term partners Bladt Industries and ISC Consulting Engineers) as well as services and maintenance for offshore wind balance of plant. All in all, these business areas have been part of Semco Maritime's offerings for almost two decades, and adding a new business area dedicated to concept and feasibility studies extends Semco Maritime's offerings to cover almost the full life cycle of any offshore wind project.

"We have found that our unique in-house technical skills and experience can be leveraged into the early concept phases of developing offshore wind sites, ensuring that proper considerations are evaluated and that the right decisions are taken at an early stage," said Tommy Flindt, director of Technology, Offshore Wind. "We have decades of successful EPC experience and feedback from sites in operation, and it will all be available to the benefit of our customers."

The offerings provided by Semco Maritime may include studies related to how to transmit offshore wind power to the onshore power grids factoring in the balance between project capital versus operational expenditures and asset availability.

"The studies for the offshore wind market cover a wide range of technical disciplines," Flindt said. "As for some selected competencies, we are partnering with other strong engineering companies in the market. These partnerships have already been tried and tested on a number of successfully delivered studies for the European, Taiwanese, and U.S. offshore wind markets where our EPC and service experience has created good value and been of benefit to our customers."

The new business area and selected references have been introduced to the Semco Maritime website.

MORE INFO www.semcomaritime.com

In December 2018, Mayflower Wind won the rights to develop a lease area that can support up to 1,600 MW of offshore wind more than 20 miles south of Martha's Vineyard. (Courtesy: Mayflower Wind)

Mayflower Wind offers Massachusetts low-cost options

Mayflower Wind Energy LLC, a joint venture of Shell New Energies US LLC and EDPR Offshore North America LLC, recently provided the public version of its bids into the Commonwealth of Massachusetts' second round of the Section 83C offshore wind-development procurement process. Mayflower Wind submitted three 800-MW proposals as well as a 400-MW proposal to the Massachusetts electric utilities. The publicly available versions of the Mayflower Wind bids are available online.

"We are very excited to submit these proposals to provide the utilities implementing the Commonwealth's offshore wind policy with a range of options," said John Hartnett, president of Mayflower Wind. "The low-price energy proposal includes strong support for research, workforce training, and economic development. Our infrastructure and innovation proposal adds significant strategic investments in port infrastructure and technology to the South Coast, boosting the fledgling offshore wind industry and the economy of the Commonwealth. Finally, our Massachusetts manufacturing proposal would further accelerate the process of Massachusetts assuming a leadership role in offshore wind by including a major new manufacturing facility that would serve both domestic and foreign offshore wind markets."

In the months since Mayflower Wind acquired a federal offshore wind lease, it has engaged with the fishing industry, local communities, tribal representatives, and local governments on the South Coast and Cape Cod, completed conceptual design of an entire offshore wind farm, filed for initial permits with the federal regulatory agency, and begun the process of pre-construction surveys.

Mayflower Wind brings deep experience and skills of its parent companies, Shell and EDP Renewables, to Massachusetts. These include successfully developing, permitting, financing, constructing, and operating offshore and onshore wind projects and offshore production facilities. Mayflower Wind draws on the experience of its parent companies who have the combined strength of more than 18,000 U.S. employees, a supply chain of more than 5,000 U.S. companies of which more than 800 are small businesses or women- and minority-owned enterprises, $400 billion in market capitalization, experience operating 6,300 MW of onshore wind in the U.S. and ongoing development and construction of 2,700 MW of offshore wind projects in France, the Netherlands, Portugal, and Scotland that are anticipated to be operational between now and 2023. This powerhouse combination gives Mayflower Wind the tools it needs to deliver projects in a safe, environmentally responsible, and timely manner.

MORE INFO www.mayflowerwind.com

Industry defies difficult market at HUSUM Wind

At the recent HUSUM Wind 2019, trade visitors used the four days of the fair to find out about technical innovations and products from about 600 exhibitors from 25 countries. The focus of the fair was on the German-speaking core market.

"We are very satisfied with the number and quality of exhibitors and trade visitors," said Arne Petersen, managing director of Husum & Congress. "Despite the current market situation, visitor numbers are surprisingly stable compared to 2017."

In a difficult time, in which the industry is experiencing strong headwinds, exhibitors along the entire value chain have with their presence at HUSUM Wind demonstrated confidence in the core market.

"The industry has delivered; it is clearly turning around," Petersen said.

"HUSUM Wind is still very attractive in its 30th year," said Hermann Albers, president of the German Wind Energy Association. "With strong innovations from all areas of the value network, the companies have shown what potential there is in wind energy."

Matthias Zelinger, managing director of VDMA Power Systems, said that, with a view to the future in the five exhibition halls, it had "become clear what wind power can contribute, far beyond the electricity system, to climate protection and sustainable energy supply."

The potential for new products and business models was also reflected in the number of participants in the Young Innovative Businesses Forum this year. With 24 participating start-ups, the platform at HUSUM Wind was one of the top 10 JiV forums nationwide. HUSUM Wind also confirmed its reputation as a sales fair.

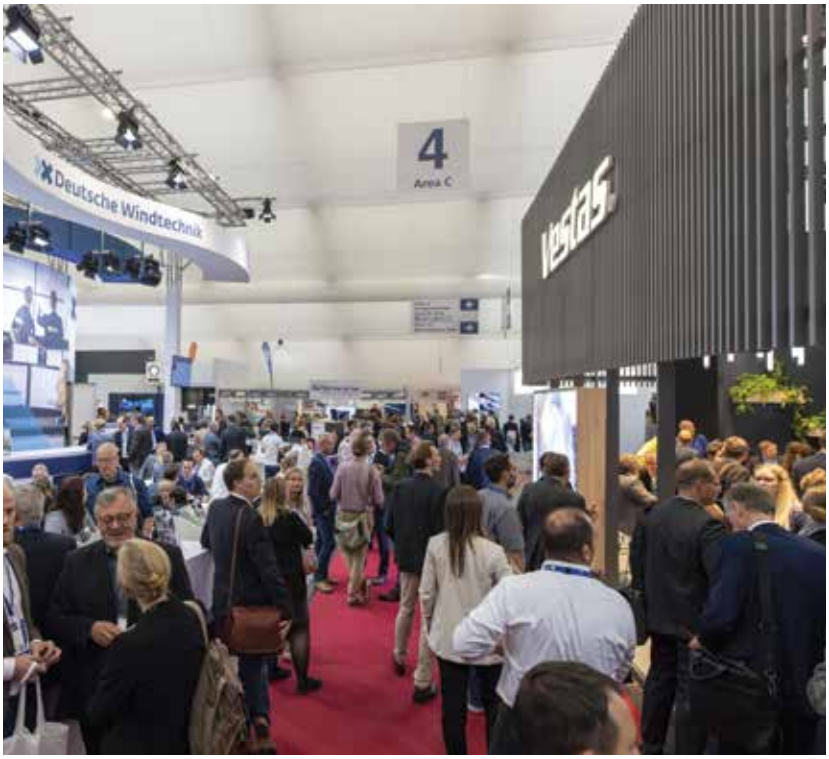
Companies reported business transactions directly from the fair as well as good contacts and discussions, especially on the second and third days of the fair. For example, on the first day, a contract was signed for four wind turbines, each with an output of 3.6 MW. By the time the gates of the trade fair closed, it was expected that up to 18,000 trade visitors would have visited HUSUM Wind.

The next HUSUM Wind will be September 14-17, 2021, when the special themes of this year's fair, hydrogen, digitalization, and repowering, will be sharpened even further.

MORE INFO www.husumwind.com

NREL selects project to address challenges of wind-wildlife

The U.S. Department of Energy's (DOE's) National Renewable Energy



HUSUM Wind mirrors the entire value chain of the onshore and offshore industry in the areas of plant construction, service, planning, financing and operation, plant components as well as raw materials. (Courtesy: HUSUM Wind)

Laboratory (NREL) has selected a new project to advance early-stage technologies for wildlife monitoring and minimization at wind-energy facilities.

This project is part of the Technology Development and Innovation program, which is funded by the DOE's Office of Energy Efficiency and Renewable Energy's Wind Energy Technologies Office (WETO) and managed by NREL. In addition to funding, the program provides recipients access to NREL facilities and expertise to develop emerging technologies that detect and deter birds and bats at wind farms.

Selectees in this program have the opportunity to conduct research at NREL's National Wind Technology Center at the Flatirons Campus, which is home to world-class researchers, wind turbines, instrumentation, and testing capabilities, as well as extreme weather conditions that allow for testing and validation in all conditions.

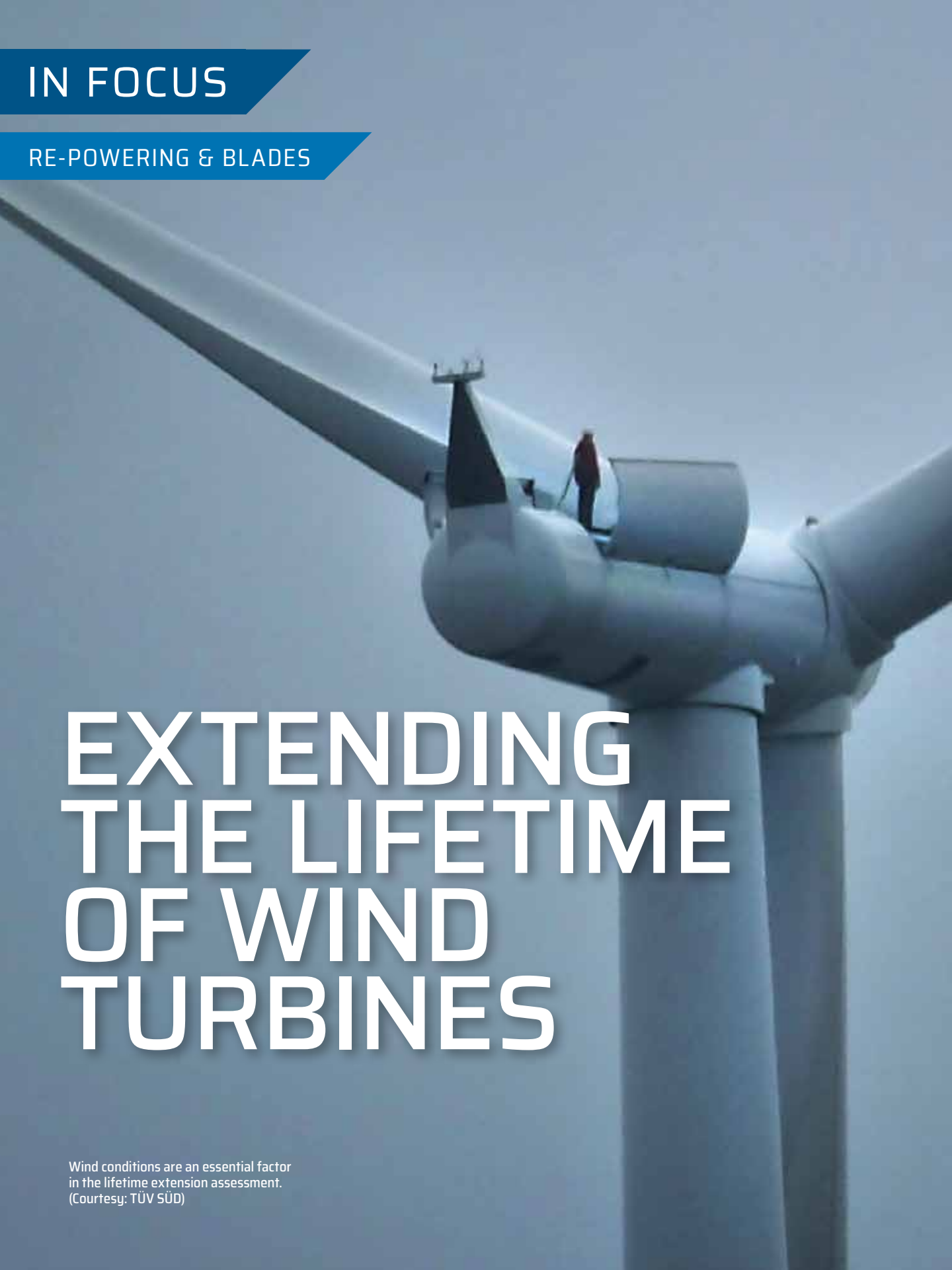
The selected project will run for 18 months and will conclude with a technical report and webinar or public presentation on the results.

The Technology Development and Innovation program at DOE's National Renewable Energy Laboratory supports efforts to reduce the impact of wind technologies on wildlife such as birds and bats. (Courtesy: NREL 35730)

Learn more about WETO's work to assess and mitigate wind's environmental impacts, and find out more about the project that was selected.

MORE INFO energy.gov

EXTENDING THE LIFETIME OF WIND TURBINES



Wind conditions are an essential factor in the lifetime extension assessment. (Courtesy: TÜV SÜD)

The results of lifetime extension assessments conducted by TÜV SÜD indicate that most turbines can continue to operate in a safe and economically viable way for several years beyond their defined service lives.

By CHRISTIAN SCHUMACHER and FLORIAN WEBER

Wind turbines have a planned service life of approximately 20 years. Nevertheless, it has been demonstrated that many turbines are able to operate beyond their design lives. In several instances, the lifetime of a wind farm may be extended through minor and low-cost repairs. In order to establish whether a wind turbine can continue to operate past its service life, a practical and analytical evaluation is carried out. In this article, TÜV SÜD explains in detail how the lifetime extension assessment is conducted, as well as the benefits of this analysis.

Wind-energy asset owners are confronted with critical business decisions as their wind farms approach the end of their operational lives. Should their turbines be decommissioned? Should they be replaced? Or can they remain in service beyond their design lives? The basic principles for assessing lifetime extension of a wind turbine have been specified by a work group created by the German Wind Energy Association [1].

The work group, formed by manufacturers, operators, technical experts, representatives from the authorities, and legal experts, has established the necessary technical requirements for ensuring continued operation in a safe and economically viable manner.

Ensuring the stability of a wind turbine is a key factor in the safety evaluation process. In particular, all the load-bearing components must be analyzed, i.e. from the rotor blades to the foundation, as well as the safety devices, the turbine control systems and the braking systems.

It is important to quantify the actual stresses and loads to which a turbine has been subjected during its operational life. This calculation is done by computer simulations that reflect both design conditions after type testing, as well as the actual operating conditions. In addition, the safety evaluation comprises an equipment inspection.

The lifetime extension assessment thus consists of two parts: an analytical evaluation and an on-site inspection. Following the analytical and practical assessments, wind-farm operators receive a status report highlighting the

In the practical part of the lifetime-extension assessment, the physical condition of the turbine is evaluated through an on-site inspection. (Courtesy: TÜV SÜD)

requirements necessary for extending the lifetime of the turbine. As a result, an accurate financial estimate of the costs involved can be generated. The report lists both opportunities and risks of continued operation and is an important tool in assisting owners with their business decisions throughout and beyond the service lives of their assets.

TIMING

The lifetime extension assessment is usually carried out during the last year of validity of the operating permit, in order to determine the most recent conditions of the turbine. Wind-farm operators are responsible for arranging the inspection in a timely fashion and for presenting the relevant documentation. In the case of medium-term budget planning, or if divestment of the turbine is being considered, it may be advisable to perform the evaluation at an earlier point in time. In these particular instances, a physical inspection is not necessary. These preliminary results, which highlight the feasibility of continued operation and when specific components are likely to need replacement, may be incorporated at a later stage into a lifetime extension assessment.

DOCUMENTS REQUIRED AND MISSING DATA

For the assessment of the wind turbine, both technical documentation and environmental operating conditions must be available. The potential duration of continued operation of the turbine is calculated based on this data. Required documentation includes the operating permit of the turbine, documents relating to its construction and commissioning, operating and yield data, repair, inspection and maintenance reports, and wiring and hydraulic diagrams. Moreover, a technical report carried out within the last year establishing the current condition of the rotor blades is required. In the case of missing data, such as technical documents and certificates, including documentation from the construction and commissioning phases, these can usually be obtained from the manufacturer. If this is not the case, comparisons with other turbines and assessments based on previous experience may be used.

WIND CONDITIONS

Wind conditions are an essential factor in the lifetime extension assessment. In order to calculate loads and stresses for the period of operation, data documenting average wind speeds, turbulence intensities, and extreme wind events for the previous 20 years are used. Operating data and data from the anemometer on the nacelle form the basis for this calculation. Should this data not be available for the entire period, long-term extrapolation may be performed using other data sets. In the case of a wind farm with a variety of capacity additions, turbulence is calculated for each individual turbine.

ANALYTICAL ASSESSMENT

During the analytical assessment, operating conditions are compared with design conditions. Continued operation is

The lifetime extension assessment thus consists of two parts: an analytical evaluation and an on-site inspection. (Courtesy: TÜV SÜD)

favorable when the historical conditions are more benign than design conditions. In particular, the actual stresses and loads faced by a turbine are compared with the stresses and loads for which the turbine was manufactured. These can be simulated using software-based methods comparing historical wind conditions with design wind conditions. As in the technical part of the assessment, all load-bearing components contributing to the structural stability of the turbine are examined: the tower and foundation, screws and bolts, the load-bearing parts of the nacelle, the shaft, the hub, the rotor blades, the braking systems and the safety functions. Following the analytical assessment, a report is prepared highlighting any immediate measures required for continued operation and specifying the time remaining until design loads are reached. The two parts of the assessment are conducted in parallel and experts in the analytical and practical evaluation processes mutually support each other.

ON-SITE INSPECTION

In the practical part of the lifetime-extension assessment, the physical condition of the turbine is evaluated through an on-site inspection. The purpose of this examination is to document any damage to the equipment and any changes in the surrounding environment of the wind farm. In particular, all load-bearing and safety-relevant components are examined in detail. Maintenance records are checked, and the actual condition of the turbine is compared with the technical documentation. Inspectors look for signs of corrosion and visible cracks and listen for unexpected gearbox noises. Moreover, a detailed investigation of any weaknesses or flaws associated with a particular type of wind turbine is carried out. The conditions of the principle components of the turbine (the rotor blade, the gearbox, the supporting structure, and the foundation) are assessed. In the event of significant damage that would compromise the safety of

DESIGN SERVICE LIFE OF WIND TURBINES

- The assumed loads factored into the turbine design by the manufacturer are based on a defined service life for the wind turbine.
- All operational and safety- and construction-relevant components and load-bearing parts of the turbine are designed, built, and dimensioned to withstand foreseeable loads and stresses caused by wind, weather, and operation for the length of this period.
- This design service life is usually 20 or 25 years — provided the specified maintenance is completed, regular inspections and testing are performed, and faults are immediately remedied. If this is the case, operators can rely on the structural stability of their turbine for the defined period.

- The design service life and period of lifetime extension are used as a basis for calculating the total service life. Registrations undertaken within the terms of the German Renewable Energy Sources Act (EEG) showed that at the end of 2016/start of 2017, more than 1,200 wind turbines in Germany had been in operation for more than 20 years, i.e. their lifetime had been extended.
- Germany's first wind turbines to be placed into operation will no longer receive EEG subsidies from the end of 2020. Market prices will thus have a major impact on the turbine operators' decision-making over the viability of lifetime extension.
- Between 2019 and 2024, the decision of whether to decommission, repower, or continue to operate will apply to about 1,500 to 2,000 turbines every year, decreasing to approximately 1,000 turbines per year from 2024.
- It is likely that repowering will not always be possible, particularly given the mandatory distance required between the turbine and the nearest residential area; in such cases, options for lifetime extension will be particularly attractive.

continued operation, immediate shutdown of the turbine could be recommended. However, in most instances, the damage discovered is relatively minor and generally caused by material fatigue and weathering. Rotor blades frequently need repairing, as they are usually subject to small cracks, erosion, or flaking. Other issues that can easily be solved include corrosion or worn cables. Finally, any changes in the surrounding environment, such as expansions in neighboring sites, must be taken into account when calculating turbulence intensities.

CONCLUSIONS

The results of lifetime extension assessments conducted by TÜV SÜD indicate that most turbines can continue to operate in a safe and economically viable way for several years beyond their defined service lives. Wind conditions at the site may have resulted in lower loads than originally estimated. As a result, the supporting structure of the turbine is often free from significant damage. Therefore, in many cases, the repairs needed to extend the lifetime of the turbine are generally minor and cost-effective. In many instances, the bolts attaching the rotor blades to the hub need replacing, as they tend to reach their design limits more quickly. Replacing these bolts is a relatively straightforward procedure that requires only a limited period of downtime.

LIFETIME EXTENSION

As wind farms age, there is a higher chance of safety-relevant damage caused by material fatigue. Nevertheless, experience gathered by TÜV SÜD shows that many turbines still have service life reserves beyond their design lives. Conducting a lifetime extension assessment helps managers and operators to determine whether continued operation is possible and to plan for the future of their assets. This assessment is also recommended in cases where the extended lifetime is to be relatively short if no further action were taken. The results of the lifetime extension assessment would be used to forecast the repair and maintenance costs likely to be incurred during the remaining life of the turbine and to plan maintenance shutdowns accordingly. Finally, the lifetime extension report is generally required by service providers after the end of the design life of the turbine or when applying for extension of insurance policies.

REFERENCE

[1] German Wind Energy "Grundsätze für die Durchführung einer Bewertung und Prüfung über den Weiterbetrieb von Windenergieanlagen (BPW) an Land" (Principles of Performance of Assessment and Examination for Lifetime Extension of Onshore Wind Turbine Generators (Bewertung und Prüfung über den Weiterbetrieb von Windenergieanlagen, BPW))

ABOUT THE AUTHORS

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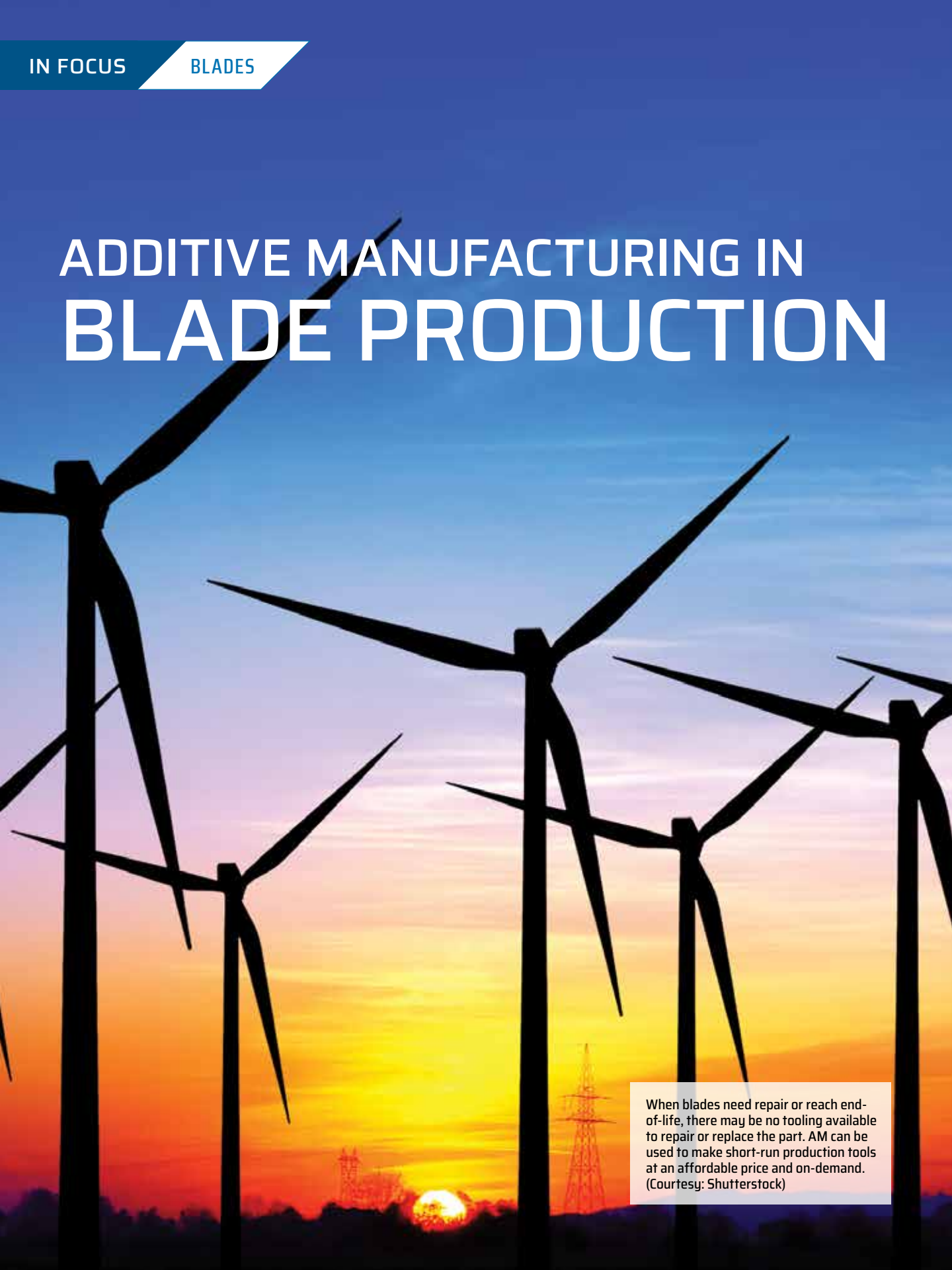
During the analytical assessment, operating conditions are compared with design conditions. (Courtesy: TÜV SÜD)

ADDITIVE MANUFACTURING IN BLADE PRODUCTION



When blades need repair or reach end-of-life, there may be no tooling available to repair or replace the part. AM can be used to make short-run production tools at an affordable price and on-demand. (Courtesy: Shutterstock)

The rise of additive manufacturing could translate into optimizing individual tower blades for their wind and turbulence patterns at each location on a wind farm.

By JACOB GOLDMAN

Additive manufacturing (AM) has been around for a little over 30 years. It brought agile development into the manufacturing world because companies could now rapidly prototype. There have been substantial scalability issues leading to no significant changes in traditional industrial manufacturing practices. However, this is rapidly changing.

The introduction of new technologies, better simulation, and a greater industry adoption is giving rise to a focus on quality, speed, repeatability, and material properties. This is fueling growth from both internal and external investment into the AM market [6].

According to Wohler's Report, "The total industry estimate of $7.336 billion excludes internal investments from the likes of Airbus, Adidas, Ford, Toyota, Stryker, and hundreds of other companies, both large and small. A surprising number of the $1-5 billion companies — many of which are unfamiliar to most of us — are investing in AM R&D" [12].

This demonstrates the shift of industry into agile manufacturing, and AM has the ability to dominate rapid prototyping, rapid tooling, mass customization, and onsite manufacturing [10, 11].

USERS AND USES

Each of these uses has notably different and sizable impacts on entire companies and their business models. In a traditional business, AM directly affects product development, manufacturing practices, and inventory with second ripple effects on accounting and supply chain. Startups and established companies alike are recognizing the power of mass customization in manufacturing where each and every product is custom [4]. An example of this in consumer markets is in the eye glassware market, where companies are introducing custom 3D-printed glasses [1].

In the wind-power industry, this could mean optimized wind-turbine blades per tower in a wind farm. In other words, the blades of each turbine can be optimized for the individual location, wind, and turbulence patterns at each and every location in the farm. Additive manufacturing is the technology that makes all this possible at a lower price-point and with shorter lead times [3].

Repair is another region where additive manufacturing can make an impact.

When blades need repair or reach end-of-life, there may be no tooling available to repair or replace the part. AM can be used to make short-run production tools at an affordable price and on-demand.

Rapid prototyping is currently being used to build and test new designs. Printed parts are entering wind tunnels as cheap and easy alternatives to composite molded or machined parts [3]. Similar parts are also being used as molds and fixtures making composite rapid prototyping possible.

In 2017, TPI Composites concluded a joint research project with Oak Ridge National Labs (ORNL) and Sandia National Labs (SNL) that collaboration demonstrated the feasibility of large-scale AM in reducing production cost, time, and environmental impact of wind-turbine blade molds. (Courtesy: TPI Composites)

In production, rapid tooling makes agile manufacturing feasible. Outfitting a production plant with jigs, fixtures, tools, and molds is now fast and has much less overhead which also means changing practices, products, and designs has a much lower opportunity cost.

The last use category of additive manufacturing is final products. The medical industry has been using AM printed parts for nearly a decade. Two examples are the affordable and highly customizable open-source prosthetics parts made by companies such as the Open Hand Project and in 3D-printed hip replacements [9]. In aerospace, 3D-printed parts can be found across Boeing's 787 Dreamliner [2]. There are even companies doing on-site production of full-size structures out of concrete such as wind-turbine towers [5].

CASE STUDY

In 2017, TPI Composites concluded a joint research project with Oak Ridge National Labs (ORNL) and Sandia National Labs (SNL). The collaboration demonstrated the feasibility of large-scale AM in reducing production cost, time, and environmental impact of wind-turbine blade molds [3]. Because AM specializes in rapid prototyping, rapid tooling, mass customization, and onsite manufacturing, it met the requirements of the Department of Energy (DOE) [8].

A 2017 DOE report reflected the interest and goals. It stated, "increasing reliability while lowering production costs [are key to] promoting a domestic industry able to meet manufacturing demands while competing globally" [8].

Part of that global competition is the prototyping phase where this study proved the feasibility in prototyping wind-turbine blade molds. As an industry, we are looking to build bigger blades. To do this, we must effectively apply new manufacturing techniques and technologies. Additive manufacturing offers a faster, more efficient, and far more

Process for 3D printing wind turbine blade molds. (Courtesy: TPI Composites)

flexible manufacturing option [10], that specializes in the rapid prototyping, rapid tooling, mass customization, and onsite manufacturing; all things critical for future competition and continued innovation.

FUTURE DEVELOPMENT

Looking forward, there are many challenges for AM to overcome to fully automate the tool-making process and to create 1000-plus cycle molds possible. For the wind industry, surface finish and accuracy are key.

The current producing of a mold with an accurate and fine surface finish requires a complex manufacturing chain very similar to that of current composite molds [3]. As a result, the core offerings of AM — time and cost savings — are nullified by the need for labor, repetitive freight, and multiple companies making margins. Therefore, surface-finish automation techniques and technologies are desperately needed.

Second, more predictable and repeatable prints are a necessity.

Without this, the manufacturing principle of Heijunka or level production occurs.

Heijunka states that no matter what happens, your output remains the same every day; this really means predict-

ability and repeatability [7].

3D-printed parts currently have enough variation in their material microstructure where heat cycling will cause lack of dimensional stability.

Once production-grade parts are achieved, factories and product will be able to rapidly adapt and work in conjunction with digital twins. Wind will power the fourth industrial revolution. Wind-power production should benefit from its advances.

ABOUT THE AUTHOR

Jacob Goldman is cofounder and CTO of Ahead Wind Inc.

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PROFILE

NORBAR TORQUE TOOLS INC.

PRECISION TOOLS FOR WIND PROFESSIONALS

Norbar is developing a battery-powered version of its EvoTorque tool. The EvoTorque uses joint-sensing software that can detect if a joint is of high- or low-rate almost immediately. (Courtesy: Norbar Torque Tools Inc.)

NORBAR TORQUE TOOLS INC.

FOUNDED
1962, became part of Norbar in 2001

HEADQUARTERS
Willoughby, Ohio

WEBSITE
norbar.com

Norbar's tools and instruments can help make the wind industry run more efficiently, reliably, and cleanly.

By KENNETH CARTER ◤ Wind Systems editor

When wind technicians are working in the field, they need quality tools that will not only get the job done, but get it done quickly and accurately.

That's how the experts with Norbar Torque Tools Inc. factor into that equation.

"What sets our tools aside is mainly quality," said Dominic Ortolani, regional sales engineer for Norbar. "With these guys operating the field — specifically operations and maintenance — they need a high-quality tool that won't break down on them in the field, because, if it does break down, these tools typically will need to be sent out for repair. You're talking about sending out from a remote site to a repair site. That's arguably almost a week of downtime that you're going to see. And every day a tower powers down, that's $6,000 in loss."

Although Norbar has served many different industries, the company jumped into the wind industry less than a decade ago with its line of high-quality torque tools.

"Norbar has identified this as a target market for a long time," said Keith Daiber, president of Norbar Torque Tools Inc. "We're heavy industry bolting specialists, so we do a lot in rail and power gen and road trucking, all kinds of industry. We're a pretty versatile company, and wind is certainly an avenue that we're chasing heavily."

EXTENSIVE LINE OF TORQUE TOOLS

Norbar provides the heavy bolting tools used in the operations and maintenance of turbines, as well as in the erection and manufacturing of the towers.

"There's a lot that we offer, and it's primarily on the operations and maintenance of these towers, the daily maintenance," Ortolani said.

Norbar's hand torque wrenches range from screwdrivers with a minimum capacity of 0.3 N•m through to wrenches with a capacity of 2,000 N•m.

Norbar's torque wrenches are used throughout the power-generation industry from the equipment manufacturers producing the plant through to power generation sites and the electricity distribution infrastructure. The features that make Norbar wrenches suitable for this industry include accuracy that exceeds the requirement of international standards, backed up with a traceable calibration certificate supplied with each wrench. Robust ratchets with a narrow engagement angle allow the use of wrenches in tight spaces.

Users of Norbar's Professional series wrenches in elevated positions such as wind-turbine nacelles will particularly appreciate their light weight and compact dimensions.

Norbar's electronic torque wrench, NorTronic®, can perform high-precision torque and torque/angle tightening and auditing of fastened bolts. NorTronic's Wi-Fi capability enables data to be wirelessly collected from the wrench either in real time or by batch data transfer at a time of the users choosing. The supplied PC software allows easy management of the collected data and set-up of the torque wrench.

Norbar now offers a range of torque wrenches up to 2,000 N•m that can be split for storage and transportation. These wrenches are easily transported and can be assembled and disassembled in seconds.

Another innovation in the torque wrench range is the introduction of 3/8" and 1/2" drive, 1,000-volt insulated torque wrenches, tested to IEC 60900:2004 and suitable for live-line working by a qualified operator.

Yet another tool in Norbar's arsenal is the EvoTorque®, which uses joint-sensing software that can detect if a joint is of high- or low-rate almost immediately. In the case of a high-joint rate, an electronic brake is applied to quickly

Users of Norbar's Professional series wrenches in elevated positions such as wind-turbine nacelles will particularly appreciate their light weight and compact dimensions. (Courtesy: Norbar Torque Tools Inc.)

stop the motor, preventing torque overshoot. This provides torque up to 7,000 N•m.

GETTING USER INPUT

Part of what makes Norbar's tools special is how they've been designed with the user in mind, taking actual cues from workers in the field, according to Ortolani.

"We would do a field demonstration of our equipment, get the field technicians hands-on with it, and get their honest feedback and then take that back to the drawing board a little bit," he said. "We've worked with some of the primary turbine manufacturers on the design of our tools in accordance with what their needs and demands are and what kind of tools they want to see in the field."

With the field testing and insight from companies within the industry, Norbar was able to get a good idea of what kind of tool it needed to provide, according to Ortolani. Once the improved tool was on the market, Norbar's distributors offered it to existing customers.

"We would provide technical expertise and consultation on it," he said. "It's just playing the cards the right way with the contacts that you have and leveraging those contacts to move up the ladder within those companies and develop a bigger picture of how we can supply tools for them."

All that boils down to how Norbar comes to understand its customers' needs, and how it can fulfill those needs, according to Ortolani.

"It always helps us to know what equipment they're currently using," he said. "And then with our understanding of the competitors in the market, we can tell them how they can benefit, not just on the qualitative side, but on the quantitative side as well — where the cost savings and analysis will come in and where the production will increase. Cost of ownership was a big, big thing for us, so whenever a customer approaches us, it obviously starts with understanding their need and if and how we can fulfill that need and then what can we do better than what they're currently using. These types of tools and this type of equipment I could try and sell all day over the phone, but it's not until I get the tools in their hands and we do a pretty extensive field test that we really see movement forward."

COMPANIES TAKING NOTICE

That hands-on attitude has made many companies take notice of what Norbar can offer them, according to Ortolani.

"We are currently working with one of the primary operations and maintenance companies within the wind industry," he said. "They are standardizing on our product. And then we are in talks with another key player to work within their company from manufacturing up to operations and maintenance implementing the Norbar product into their line and supplying them with service equipment so they can do their calibrations. So, we have two pretty big players under our belt, and we're talking with them on a nationwide scale and beyond. That's been years in the making."

The first project has taken three years of field tests and

Norbar offers a range of torque wrenches up to 2,000 N•m that can be split for storage and transportation. (Courtesy: Norbar Torque Tools Inc.)

Norbar has put in a lot of due diligence in its eight years in the wind industry, which is why the company can stand behind its high-quality tools. (Courtesy: Norbar Torque Tools Inc.)

contract talks to come to fruition, while the latter project goes back to 2012, according to Ortolani.

"Now we're really seeing progress, and these two dominoes are really making the rest of them fall for us I think," he said.

Norbar has put in a lot of due diligence in its eight years in the wind industry, which is why the company can stand behind its high-quality tools, according to Daiber.

"We've got a tool that does perform to industry standard; it gives customers choices, and that's always a good thing," he said.

Another tool in development is a battery-powered version of the EvoTorque.

"It's almost the exact same tool as our EvoTorque corded tool," Daiber said. "You're going to be running on 18-volt batteries — same gearbox, the same software technology, same capabilities. We have a single speed and a dual speed version of it. It's more or less a complete clone of our existing electronic tool. It's just a little bit more versatile since it is able to be used without a cord."

HISTORY AND EXPERIENCE

Even though Norbar's involvement with wind only goes back eight years, the company itself was actually a British company that began in the 1940s.

"My dad started the company in 1962, and we became affiliated with Norbar in the late '70s, early '80s as a distributor," Daiber said. "And then, in 2001, they approached us and bought into our business as equal partners. So, we became part of the global Norbar team. And in 2017, we were acquired by Snap-on. We're still Norbar Torque Tools Inc., which is part of Norbar Torque Tools Limited, but it's all part of the Snap-on group."

With all that history and experience behind it, both Daiber and Ortolani expect Norbar to continue to grow in its wind endeavors.

We're continuing to grow pretty consistently within wind," Ortolani said. "I think we all know that the trend — not just domestically but globally — for where we resource our energy is going toward alternative-energy methods, such as solar and wind. And I think as we continue to provide a full-service and product solution, we can support these customers on a national basis with a full comprehension of what their tooling needs are. Being able to provide that to the customer helps Norbar stand on its own pedestal. So, as the wind and renewable energies continue to grow, so will Norbar within it. And I think we see a big opportunity there."

Daiber also sees even more opportunity as the wind industry adjusts to less government assistance.

"Some of the hurdles early on were tax-incentive related where the market went up and down depending on what the government was offering," he said. "I think we're past that now. As the system gets more efficient, it's just the right way to go."

Lee Lippert

President and Founder ◤ DSX Products

"I see DSX extending the life of the equipment, which makes the payoff easier and will make the efficiency that much greater."

◤ What can DSX offer the wind industry?

Two things are important: We can increase production at a relatively low cost, and we can increase the useful life of both internal mechanicals and external surfaces.

◤ How did you discover your product would be advantageous to the wind industry?

I had a customer who was a retired nuclear power plant R&D engineer. In that capacity, he got connected as a consultant to wind energy activity with a large company. For no reason, other than he was hugely impressed with DSX, he volunteered that I needed to get into the industry.

He said, "Not only are you going to extend the life of the equipment, but you will increase the productivity," and he told me what to do. He also told me no one in the industry has addressed the issue of modifying friction, and they live with whatever becomes the solution of the day as long as it's easily accepted. And the biggest issue for them is they truly believe bigger is better, and all the industry wants is bigger units.

I have a customer who's looking into what they can do to supply some assets with DSX products that they are now buying from me for other applications.

The bottom line is I was told I should use DSX wax on the blades and the hub, and I have to push to get the entire blade waxed, not just the leading edge. If they start using the wax, they're going to want to use it on the leading edge, because that's where they have damage that they can see and have to fix. But some of them don't understand the benefit of better aerodynamics. My engineer colleague said they should, but sometimes it's easier to approach obvious, easy applications, instead of working out the whole process.

He said there is something that grows on the hub, like an algae in parts of the world they may refer to it as a fungus, and he said they don't understand they need to keep that algae or fungus from accumulating. There also is some reduction in heat from the wax, so he said he would also wax the nacelle.

He said the next issue, and the biggest issue, is to put DSX Extra, the engine additive, in the reduction gears. He said that's where you're going to give them the greatest benefit, because you're going to make those gears work better, and with the temperature reduction we get, he said you will seriously improve the lubrication process and extend the useful life of the lubrication, whatever they're using. And he knew at that point that you could mix DSX Extra with any of the lubricants that anybody uses. It'll blend.

◤ Your products are based on embedded-particle technology. Could you explain what that is, and how it's a good fit for wind O&M?

When you look at any manufactured product under a microscope, it might look and feel smooth, but it's not. You'll see voids in the material called asperities. Some people would call it pitting, but asperities is the technically correct word for those little voids in the material.

The fluoropolymer particles do several things that are valuable when they're in the lubricant. If you were to take your engine apart, you would have an accumulation of sludge and varnish and basic "yuck."

The fluoropolymer particles will attack that yuck. It'll knock the varnish or the sludge loose. It will end up in a filter. As long as your filter is a bypass filter, your oil will continue to lubricate. The result is a better fit and finish and less heat buildup.

With the wax, and still with the fluoropolymer, we're still filling it and making everything smoother, whether it's metal, glass, fiberglass, or whatever. And because it's so smooth, there's no place for dirt or whatever to adhere to it.

◤ What are some of DSX's proudest achievements?

When I was at the Cummins dealer, this customer rebuilt his engine at 1-million miles and started using DSX Extra in the engine oil, transmission fluid, and drive axle lube. After 2 million miles with DSX Extra, the top of a cylinder came off. The engine was then rebuilt at a Cummins engine rebuild facility. When he started with DSX Extra, he changed oil at 18,000 miles. He has been changing oil for

years at 30,000 miles or more. His only engine expense with DSX Extra has been two sets of injectors.

Usually in an engine rebuild, it is possible to identify the cause of the failure. The Cummins mechanics found no indication as to cause and decided it was most likely metal fatigue. The Cummins dealer said they normally rebuild engines in the 700,000- to 800,000-mile range. He said in his 15 years with the company — this was the supervisor — he said he thinks they had done two engines at a million miles, and this is the only time they had done one at 2 million miles.

For the racing achievement, a colleague of mine applied my grease additive to the wheel bearings. It's not a direct application. He mixed it with his previous lubricant.

Before doing that, it took two people to push the car around the shop. Now it takes one person — one hand on the rear spoiler — to push it anywhere he wants it. That's how much we've reduced friction. The result is more horsepower available to go fast since there is less friction to overcome. This race shop builds and supports four cars racing in Trans Am 2 and SCCA Sprint 2 (500 HP engines).

With a second racing operation, the team owner reported that, before DSX Extra, the camshaft was dry when it was in the shop and rust accumulated on the camshaft. The engine is a 250HP overhead cm Ford product. With DSX Extra in the engine oil, the cam shaft is always lubricated — there is no rust.

This team manager sends the engine to the factory every two years for a "check-up." This year, when the engine was returned, the builder mentioned to the car owner that he had not replaced the bearings. When asked why, the builder responded, "There was no measurable evidence of wear." After two years of racing — no evidence of wear.

What do you hope to accomplish by introducing your product to the wind industry?

What is the problem with the reduction gears that burn up in wind energy? The issue becomes heat, and eventually something jams up or burns up, and then the whole thing falls apart.

When used in a truck, the temperature gauges were checked periodically, because the results were hard to believe. Engine oil was 195 degrees F on Day 1. With DSX Extra in there, it went down to 150 degrees. The same results happened in the transmission fluid. A transmission and an engine are not comparable to a reduction gear, but the drive axle, or the differential on your car, or the drive axles on the truck, which are basically really big differentials, are directing the flow of lubricant to do a job, so the drive axle or differential is very similar to a reduction gear. The lube temperature of the truck went from 185 to 125 degrees and stayed there while we were keeping those records for more than six years.

Now, let's go back to that differential that's similar to a reduction gear. The Arrhenius Rate Rule states that for each 10 degrees C (18 degrees F) change in lubrication temperature, there is a measurable change in the useful life of a lubricant. That is, a 10 degree C increase reduces the useful life by half, and a 10 degree C reduction in temperature increases the useful life by double. We went from 185 to 125 degrees, so the first 18 degrees meant we just doubled the life of the lubricant. The next 18 degrees, we double it yet again. And the next 18 degrees, we double it yet again, and we still have some extra degrees worth of reduction of extended life.

What I'm saying is we're going to lower the temperature by upwards of 60 degrees in a reduction gear. We're going to keep it cleaner, and we'll extend the useful life of the lubricant significantly. Basically, I know from what we've done that we can accomplish similar results with wind energy.

Now, you start putting those numbers together, let's go back to my 2 million miles. According to the trucking industry, that's worth about 44,000 hours.

So, basically what I'm saying is we're going to lower the temperature by upwards of 60 degrees in a reduction gear. We're going to keep it cleaner, and we'll extend the useful life of the lubricant significantly.

Basically, I know from what we've done that we can accomplish similar results with wind energy.

Where do you see wind in the next decade, and DSX's place in that future?

Reading the literature, I'm going to say that there is enough interest in politics to substantially increase the wind-energy industry. I know the percentage of improvement that if they do what I suggest — wax the blades, the hub, and treat the reduction gear — I know how much DSX products should improve the energy output.

Basically, I see DSX extending the life of the equipment, which makes the payoff easier, and will increase efficiency by (1) reducing friction internally and increasing the life of lubricants and (2) improving and maintaining aerodynamics of blades by reducing surface friction.

MORE INFO dsxproducts.com

Ian Baylis, managing director of Seacat Services, and Matthias Reiker, finance director of Triton Knoll. Triton Knoll will be the next major offshore wind construction project to enter U.K. waters. (Courtesy: Triton Knoll)

CONSTRUCTION

Triton Knoll selects Seacat Services for offshore support

Class-leading offshore energy support vessel (OESV) operator Seacat Services has signed a long-term deal to support the construction phase of Triton Knoll offshore wind farm.

The contract, which includes options for further vessel charters, will initially see two Seacat Services OESVs — one 26-meter and one 24-meter catamaran — operating out of Triton Knoll's new Grimsby construction base, providing specialist crew transfer and logistical support at the 90-turbine, 857-MW project off the U.K.'s East Coast.

With offshore construction set to commence in the first quarter of 2020, the first of the two vessels will begin preparation works at the project this winter, with the second set to join her in April 2020. Both are set to remain on the project until the end of 2021.

Triton Knoll will be the next major offshore wind construction project to enter U.K. waters when the first components are installed next year, and it has already made significant progress during the installation of the onshore electrical system. Once fully operational, Triton Knoll will be capable of generating enough renewable energy for the equivalent of more than 800,000 typical U.K. households.

Throughout construction, the wind-farm project continues to support the ongoing development of the domestic supply chain and recently launched a local recruitment drive for long-term operations technicians on the project. The contract with Isle of Wight-based Seacat Services extends a relationship that has already seen the project owner and vessel operator work together at Galloper Offshore Wind Farm.

Seacat Services' entire fleet of 14 state-of-the-art OESVs has been built in the U.K., with two further catamarans under construction at the Diverse Marine shipyard in Cowes.

"We're delighted to bring Seacat Services into the Triton Knoll team, further strengthening our project

presence in Grimsby and reinforcing our commitment to the U.K.'s offshore supply chain," said Matthias Reiker, finance director for Triton Knoll. "It is vital that the construction of the project is conducted as efficiently as possible while meeting our highest safety standards. In light of this, Seacat Services has proved a natural fit as a vessel provider, and we look forward to progressing our state-of-the-art project with them."

The deal reaffirms the expertise of Seacat Services in managing complex logistical charters for large-scale offshore wind construction projects. For the duration of the contract, the pair of Seacat Services vessels will be operating out of the Port of Grimsby and will work in conjunction with the onsite Service Operation Vessel (SOV) as part of a shift-based approach that will keep them available on a 24-hour basis at the height of construction activity.

"During the time-sensitive offshore wind construction phase, the importance of a finely-honed approach to vessel management cannot be understated," said Ian Baylis, managing director of Seacat Services. "It not only ensures maximum 'time-on-turbine' for project technicians to keep the project on track but can also create wider operational efficiencies that have an impact across the board. Having worked out of Grimsby previously, we're looking forward to returning later this year and getting the project underway."

MORE INFO www.tritonknoll.co.uk

CONSTRUCTION

ALLETE Clean Energy celebrates record-setting year

ALLETE Clean Energy is in the middle of its biggest wind-energy construction year.

ALLETE Clean Energy is poised to nearly double its carbon-free wind capacity to more than 1,000 MW with three new wind farms under construction in 2019 and 2020. Its renewable wind projects will support the economies of local, rural communities in seven states with jobs, taxes, donations, and volunteer activities.

New projects include the Diamond Spring wind site in Oklahoma that will sell renewable wind power to Walmart, Starbucks, and Smithfield Foods; Diamond Spring will be the largest wind facility owned by ALLETE Clean Energy — producing enough power for 114,000 homes and increasing ALLETE Clean Energy's total wind capacity to approximately 1,000 MW at nine sites. Other projects are the Glen Ullin wind site in North Dakota that will sell energy to Northern States Power, an Xcel Energy subsidiary; and the South Peak wind farm in Montana that will sell its wind power to NorthWestern Energy.

"The wind-energy industry is creating meaningful economic growth for state and local governments, landowner partners, vendors, and employees across the country," said ALLETE Clean Energy President Allan S. Rudeck Jr. "These opportunities will continue to grow as society demands cleaner forms of energy. Our ALLETE Clean Energy team is committed to answering the call to transform the nation's energy landscape while creating growth for communities where we operate and building value for ALLETE shareholders and our customers."

Wind technician is the second-fastest growing occupation in America, and ALLETE Clean Energy's continued growth and investment in clean energy means the company will soon need wind technicians in Oklahoma, North Dakota, and Montana while maintaining its current sites in Pennsylvania, Iowa, Oregon, and Minnesota. The company has grown from four employees in 2011 to more than 80 in 2019 while delivering increasing amounts of clean and affordable energy to its customers.

As a Yellow Ribbon company, ALLETE Clean Energy also is committed to hiring and supporting veterans, military members, and their families. With their technical skills and team-oriented work experience, veterans and service members find jobs in the renewable wind sector at a 67 percent higher rate than in other industries.

"Our talented employees are at the heart of our success, and as we grow there will be more opportunities to join our team," Rudeck said.

MORE INFO www.allete.com

CONSTRUCTION

Pattern Development begins operations at Grady Wind Power

Grady Wind in Curry County, New Mexico. (Courtesy: Pattern Development)

New Mexico's newest wind-power facility is now up and running. Pattern Energy Group 2 LP ("Pattern Development") recently completed construction and began operations at its 220-MW Grady Wind facility in Curry County, New Mexico. This is the third and final phase of a 544 MW suite of wind projects, which now represents the largest investment in clean power in the history of New Mexico.

"The successful completion of Grady Wind represents an important step in New Mexico's evolution as a major renewable energy producer," said Mike Garland, CEO of Pattern Development. "As the leading wind

developer and operator in New Mexico, we are proud to be helping position New Mexico as a wind-energy leader. We also plan to ramp up construction in early 2020 on more than 800 MW of new wind facilities in central New Mexico, creating hundreds of new construction jobs and generating billions of dollars in economic impact. As wind- and solar-energy development grow throughout the state, New Mexicans will reap the economic benefits."

The construction phase of Grady Wind created hundreds of jobs for New Mexicans, and it is now delivering additional economic benefits including land-lease payments to local landowners and tax revenue for the host communities of eastern New Mexico. The facility employs approximately 20 full-time personnel for ongoing maintenance and operations.

Grady Wind is using 84 Siemens Gamesa 2.625 MW wind turbines with 120-meter rotors. During each year of operations, the 220-MW facility will generate energy equal to the needs of nearly 90,000 homes. Grady Wind has a 25-year Power Purchase Agreement for 100 percent of the energy produced, and it will deliver wind power across the Western Interconnect transmission line that was also developed and successfully placed into service in 2017 by Pattern Development.

MORE INFO www.patterndev.com

INNOVATION

Siemens Gamesa builds world's largest blade test stand

Siemens Gamesa Renewable Energy (SGRE) has begun construction of the world's largest wind-turbine blade test stand in Aalborg, Denmark. The site will be capable of performing full-scale tests on the next generations of SGRE rotor blades and is expected to be fully operational before the end of 2019.

This significant R&D investment

The first tests on the stand will be on the 94-meter-long blades for the SG 10.0-193 DD offshore wind turbine. (Courtesy: Siemens Gamesa)

in extensive testing will represent additional savings for SGRE's clients in the future. Such high value-adding R&D activities enable the company to significantly reduce the risk of technical issues and simultaneously deliver wind turbines that are innovative and reliable.

"The first tests will be on the 94-meter-long blades for the SG 10.0-193 DD offshore wind turbine, which are almost the same length as one soccer field," said Vicente García Muñoz, head of Validation Means Management at SGRE. "We are, however, building the test stand to accommodate the blade sizes that we will see in the future."

The gigantic structure in Aalborg will have more steel rebar reinforcement per square meter than a wind-turbine foundation, so that it has the capability to accelerate the test and prove full reliability over the lifetime of the blade in the shortest possible time, while respecting IEC regulations.

MORE INFO www.siemensgamesa.com

INNOVATION

Chartwell expands to meet demand for next-gen vessel design

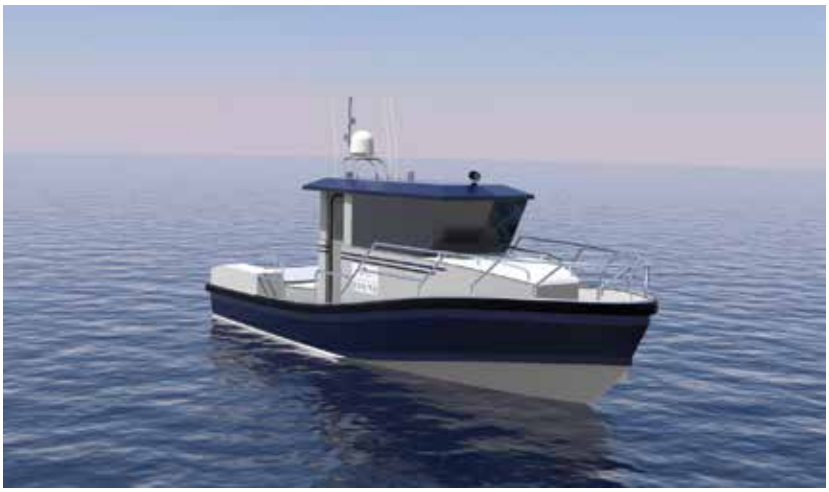
Chartwell Marine, a pioneer in next generation vessel design, has announced significant investment and growth in its team as it responds to growing global demand for its specialist vessel design services. In particular, Chartwell's commercial activity over the past 12 months has been driven by growth markets as such offshore wind and vessel hybridization, alongside a clear need for the "next generation" of specialist workboats that respond effectively to new operational requirements and demands.

To support an increasing number of global vessel design and consultancy contracts, Chartwell is investing in three key areas: The first is in personnel, with two new permanent staff joining the seven-strong specialist design team, and the appointment of reputed naval architect, Professor Bob Cripps, as non-executive director. The second is in a new Southampton HQ at Deacons Boat Yard, Bursledon, which Chartwell's expanding team will use as a hub for serving clients across Europe, the U.S., and Asia. The third is a significant investment in software and training for all members of the team.

The emergence of offshore wind across these regions has been a key driver of innovation in vessel design, with vessel operators in established markets seeking new crew transfer vessels (CTVs) that capitalize on lessons learned to date — while new offshore wind markets such as the U.S. and Taiwan look to refine this proven formula for application in new operating environments.

Launched in late 2018, Chartwell Marine's Chartwell 24 catamaran has been designed to meet these needs and has generated substantial interest from the international offshore wind development community. The business received its first two Chartwell 24 orders from class-leading vessel operator, Seacat Services, earlier this year.

Simultaneously, increasingly stringent emissions regulations worldwide are leading maritime businesses, including offshore wind vessel operators and port authorities, to carefully consider their carbon footprints, making the design of effective hybrids increasingly important.



In conjunction with U.K. boat builder Wight Shipyard Co., Chartwell Marine unveiled the first Chasewell 9-meter hybrid patrol boat in June 2019. (Courtesy: Chartwell Marine)

Chartwell Marine is swiftly establishing a strong track record in the area of hybrid propulsion, having led on a number of pioneering projects over the past 12 months. In conjunction with U.K. boat builder Wight Shipyard Co., the company unveiled the first Chasewell 9-meter hybrid patrol boat in June 2019—a vessel design which will set new standards for clean, low-cost port operations.

In addition, Chartwell Marine was selected by a leading U.S. institution to design and specify build for a unique U.S. hybrid vessel. The 65-foot high-performance catamaran has been designed to meet EPA Tier 4 emissions standards, setting a benchmark for vessel operators and boat builders in the U.S. and further afield.

These high-profile projects have been accompanied by a wide range of bespoke design briefs, responding to the operators' unique requirements—which include the Catchwell fishing vessel, Chartwell Rib and several new yacht designs capitalizing on lessons learned from the rapidly developing workboat market. Each design leverages Chartwell Marine's R&D expertise—particularly in the area of hull design, where computational flow dynamics (CFD) modeling and scale prototype model testing has been used to reduce drag and improve seakeeping for superior speed and performance, while also lowering emissions.

MORE INFO www.chartwellmarine.com

MAINTENANCE

AI engine developed for blade-damage detection

Sulzer Schmid, a Swiss company pioneering UAV technology for rotor blade inspections, and NNAISENSE, a world leading artificial intelligence specialist, have partnered to develop an artificial intelligence engine to automatically detect rotor-blade damages on wind turbines. This leapfrog technology is expected to bring the twin benefits of improving the productivity and consistency of blade-inspection processes.

With this new development effort, the two partners are aiming to build the industry's most powerful artificial-intelligence engine able to recognize damages based on inspection-image material. The initial version will be able to flag all areas of concern on any given damaged blade. Ensuing upgrades will add other capabilities, such as the ability to establish damage categories and severity levels.

"Maintaining the structural integrity of rotor blades is critical to maximizing energy output and ensuring the safe operation of wind turbines," said Faustino Gomez, CEO of NNAISENSE. "We are convinced that we will be able to transfer our extensive expertise in surface defect recognition from other industries to the wind industry and are looking forward to our cooperation with Sulzer Schmid, an innovator in its own space."

The autonomously flying drones of the 3DX™ Inspection Platform of Sulzer Schmid assure high-definition quality and consistent image acquisition time as well as 100-percent blade coverage while minimizing human errors and operational risks. The cutting-edge image assessment tools of the platform ensure detailed and efficient damage assessment. With the support of an AI-enabled inspection software, the review work of blade experts will be greatly facilitated. Instead of having to review the entire surface of the blades, they will simply need to focus on the pre-selected areas of concern. This technology progress will not only significantly boost the productivity of the reviewing teams but will also improve the quality of damage annotation processes.

"Maximizing end-to-end productivity is a key success factor in the highly competitive market of wind-turbine inspection solutions," said Christof Schmid, COO and co-founder of Sulzer Schmid. "Thanks to our collaboration with NNAISENSE, we will be able to push the envelope in this area and significantly advance the automation capabilities of our inspection platform."

"We are very excited about our collaboration with NNAISENSE, a true leader in the visual recognition of

The initial version of the AI engine will be able to flag all areas of concern on any given damaged blade. (Courtesy: Sulzer Schmid)

surface damages by means of AI," said Tom Sulzer, CEO and co-founder of Sulzer Schmid. "This will further enhance the added value we provide for our customers and partners."

MORE INFO www.sulzer-schmid-labs.ch

MAINTENANCE

Rotos 360 completes offshore blade repair at Westermost Rough

For nearly a decade, Rotos 360 has developed its position as a global market leader in turn-key solutions for onshore and offshore wind-turbine blade inspection, preventive maintenance, and repair technology. Part of James Fisher and Sons plc, the company has recently completed a successful offshore internal blade repair campaign alongside partners, SGRE, at Westermost Rough Windfarm.

As part of the six-month project, completed on time and within budget, Rotos 360 provided the wind farm with a full turnkey solution, which included labor and vessel supply and full inspection and repairs as well as a follow-up analysis.

"Rotos 360's professionalism was evident right the way through the project, from the conception and planning of the works, through the project execution and into the reporting and documentation," said John Dykes, senior project manager at SGRE. "Their commitment to safety and quality was exemplary and was a key factor in the project reaching a successful outcome."

Westermost Rough Wind Farm is an offshore wind farm about 10 kilometers northeast of Withernsea, off the Holderness coast in the North Sea. It has 35 wind turbines and covers an area of approximately 35 square kilometers.

Rotos 360 carried out 38 internal blade repairs. The project was led by Rotos 360's Project Manager Simon Wood and a SGRE technical project manager with the repair works completed by the Rotos specialist complex blade teams.

Westermost Rough Wind Farm is an offshore wind farm about 10 kilometers northeast of Withernsea, off the Holderness coast in the North Sea. (Courtesy: Siemens Gamesa)

"We would like to thank SGRE and the Orsted site team for its support over the last six months in delivering a safe project, on time and within budget," said John Galliford, operations director at Rotos 360. "This project has further complemented our 100-percent safety track record with zero lost time incidents. Since 2013, we have grown consistently through our innovative, forward-thinking solutions to complex blade repairs, a multi-skilled workforce, and trusted reputation."

Rotos 360 is part of James Fisher and Sons plc, a leading provider of specialist services to the marine, oil and gas, and other high assurance industries worldwide. Rotos 360 is a specialist in wind-turbine operations and maintenance in onshore and offshore environments. The company has the expertise to identify and repair damage, excessive wear, and other potential issues that can affect wind-turbine blades. By using advanced aerospace-grade composite repair technology, Rotos 360 can ensure maximum restoration, even in inclement weather conditions.

MORE INFO www.rotos360.co.uk

MAINTENANCE

Checkmate launches Atom Xtreme self-retracting lifeline

Checkmate, the U.K.-based Pure Safety Group (PSG) brand, unveiled its new Atom Xtreme 6-foot self-retracting lifeline (SRL) in North America. The product is significant in that it is the smallest and lightest fall arrest block in the world and one of a select few Checkmate products available in North America.

"The Atom Xtreme is a totally new concept in design engineering, featuring a revolutionary triple micro pawls lockout system and full internal braking mechanism never before seen in an SRL," said Oliver Auston, chief innovation officer for PSG.

Auston added that the brand's expansion outside of Europe was part of its strategy when Checkmate joined the PSG family in 2018. The first Checkmate product launched in North America, the TR3 tripod for confined space rescue and lifting, was announced in April 2019.

The Atom Xtreme's lifetime is made of Dyneema® webbing. It features three micro pawls that operate

The Atom Xtreme 6-foot self-retracting lifeline. (Courtesy: Pure Safety Group)

The Global Wind Organisation (GWO) is a non-profit focused on providing standardized safety training and emergency procedures across the industry worldwide. (Courtesy: GWO)

independently for faster lock on. Its internal slipping brake controls the energy from a fall without the need for an external energy absorber. The load-bearing steel chassis is internal and hot rolled to provide a structural metallic core and protected by durable composite external protective housing. The product's swivel incorporates a fall indicator that clearly shows if the device has been subjected to a shock load and has a 360-degree rotation and 180-degree pivot to ensure the block remains in the correct orientation in any working condition. Connector options include steel and aluminum snap and rebar hooks. The alloy scaffold hook is rated for 5,000 pounds and gate-rated for 3,600 pounds. The 25/32-inch eye or the fall indicating swivel top connection allows connection to a range of karabiners and rebar hooks, and the external tail webbing allows for easy reach when attached to the red D-ring.

The SRL is offered in single and dual configurations and accommodates a user weight of up to 420 pounds. It meets ANSI Z359.14 2014 Class A and ANSI A10.32:2012 standards and OSHA 1920 and 1926 Subpart M.

MORE INFO www.puresafetygroup.com

MAINTENANCE

North American firms join to focus on wind safety

North America's leading wind-power companies are joining together within the Global Wind Organisation (GWO), a non-profit focused on providing standardized safety training and emergency procedures across the industry worldwide.

Members of the GWO North America committee represent wind-turbine manufacturers and owner-operators including:

- Brian Walencik, GE Wind, Onshore (Chair).
- Gary Aucoin, Equinor.
- Karl Delooff, Acciona Energia.
- Adell Heneghan, E.On Climate & Renewables.
- Michael Hanson, GE Renewables – Offshore.
- Isabelle Le Beau, Enercon.
- Autumn Lewis, The Nordex Group.
- Dan Ortega, Vestas.
- Geoffrey Schmidt, Siemens

Gamesa.

◤ David Yang, Ørsted.

A partnership of leading global companies, GWO is responsible for a portfolio of training standards designed for the industry, by the industry.

Training modules include basic safety, basic technical, advanced rescue, enhanced first aid, and blade repair with new rigger signal person training standard now available. Training records are verified online through the GWO WINDA database, allowing companies to check the certification status of their employees and potential recruits.

"The wind-turbine industry is growing as the demand for renewable energy is accelerating," said Brian Walencik, chairman of the GWO North America committee and EHS Leader for GE Wind Onshore. "The challenge we all face is hiring qualified technicians who have recognizable safety training and technical skills so they can more efficiently and effectively help meet demand while reducing total injuries."

Highlights of the growth of the wind turbine industry include:

◤ In April, renewables eclipsed coal generation in the U.S. for the first time. The Energy Information Administration (EIA) estimates renewables outperformed coal by 16 percent in April. Wind energy is now the lowest-cost option for new electricity generation in Canada.

◤ Approximately 11 GW of wind capacity is scheduled to come online in 2019 in the U.S., which is the largest amount of capacity installed since 2012. The annual growth rate of wind energy is 20 percent for the past 10 years in Canada.

◤ The U.S. wind industry now employs a record 114,000 men and women, according to the American Wind Energy Association (AWEA). In Canada, the employment growth rate is similar.

"The role of our committee is to determine the best ways to collaborate on standardized training and procedures to benefit the industry, training providers, our employees, and contractors," Walencik said. "At the end of the day, the goal is simple: safety."

MORE INFO www.globalwindsafety.org

The SG 4.5-145, a benchmark solution for sites with medium winds, has been designed to offer a flexible rating ranging from 4.2 to 4.8 MW. (Courtesy: Siemens Gamesa)

◤ MANUFACTURING

Siemens Gamesa reinforces partnership with project expansion

Siemens Gamesa has been selected by MidAmerican Energy Company for the Southern Hills Expansion wind-power project, which will feature 21 SG 4.5-145 wind turbines, operating at 4.8 MW, and will be in Iowa. This project also features the company's premier service and maintenance agreement for three and a half years.

This turbine model, a benchmark solution for sites with medium winds, has been designed to offer a flexible rating ranging from 4.2 to 4.8 MW, increasing its adaptability to be configured for optimal performance in each individual project, achieving maximum returns.

"We are once again proud to have been awarded a project by MidAmerican Energy Company, strengthening our long-standing relationship with them," said José Antonio Miranda, CEO of Onshore Americas at Siemens Gamesa Renewable Energy. "We have had great success with the SG 4.5-145 wind turbine, with over 1.4 GW sold in the U.S., Canada and Mexico, and are excited to continue growing that number."

Siemens Gamesa has installed more than 10,000 wind turbines in the U.S. totaling about 20 GW of installed capacity. In Iowa, Siemens Gamesa has installed nearly 1,400 wind turbines for a total of almost 3.5 GW. Of that, 1,164 units for a total capacity of nearly 3 GW are with MidAmerican Energy Company, highlighting the strong collaboration of both companies.

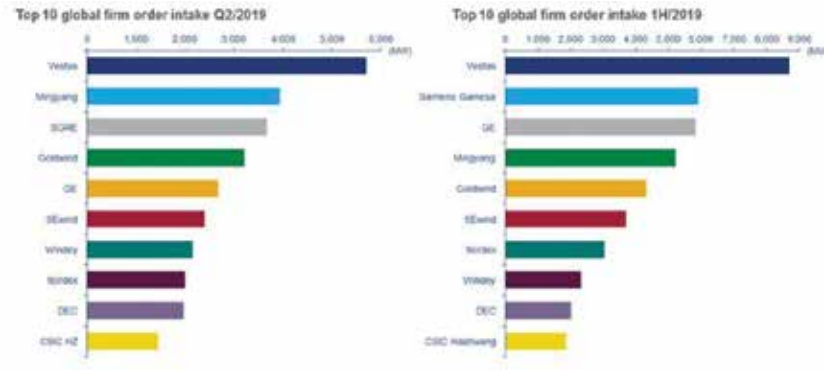
MORE INFO www.siemensgamesa.com

◤ MANUFACTURING

Wind turbine order capacity hit a record high in Q2 2019

Global wind-turbine order intake increased 11 percent YoY, overtaking the previous record set in Q4 2018 by 13.2 GW, according to new research from Wood Mackenzie.

As noted in the Wood Mackenzie report, "Global Wind Turbine Order Analysis: Q3 2019," developers globally



Vestas won the largest share of order capacity for the fifth straight quarter, enjoying the best quarter for an OEM in any year. (Courtesy: Wood Mackenzie)

ordered a record 31 GW of wind-turbine capacity in Q2 2019. Demand in China and the U.S. contributed to a total of 79 GW ordered over the last four quarters, despite a decrease of 41 percent YoY in Europe during Q2. China and the U.S. enjoyed top quarters for capacity ordered as developers rushed to procure turbines with sufficient time to commission projects before 2020 subsidy deadlines in both countries.

"Developers in China ordered more than 17 GW in Q2 2019, a 267 percent uptick YoY compared to Q2 2018; 71 percent of firm-order capacity was secured in the Northern region's onshore wind market in Q2 2019," said Luke Lewandowski, Wood Mackenzie director of Americas Power & Renewables Research. "The order volume for five major developers in China exceeded 1 GW last quarter. The record quarter in China included more than 3 GW of offshore capacity, nearly 2 GW more than in Q2 2018 and a 800 MW increase on the previous quarterly record in the country (Q1 2019). This added to a backlog of nearly 12.5 GW."

Vestas won the largest share of order capacity for the fifth straight quarter, enjoying the best quarter for an OEM in any year.

"Despite a massive quarter for orders in China, diversity in the market — illustrated by seven OEMs with more than 1GW of order capacity — prevented a dominant leader, which allowed Vestas to retain the top spot," Lewandowski said. "Eight of the top 10 onshore models in Q2 are manufactured by Chinese OEMs, six of which made the top 10 for the first time ever. All six were new models that had never been ordered publicly prior to Q2. Vestas was the only non-Chinese OEM with any models in the top 10."

Order intake in the 4.0-4.99-MW segment increased for the fifth consecutive quarter, exploding to more than 9 GW of orders.

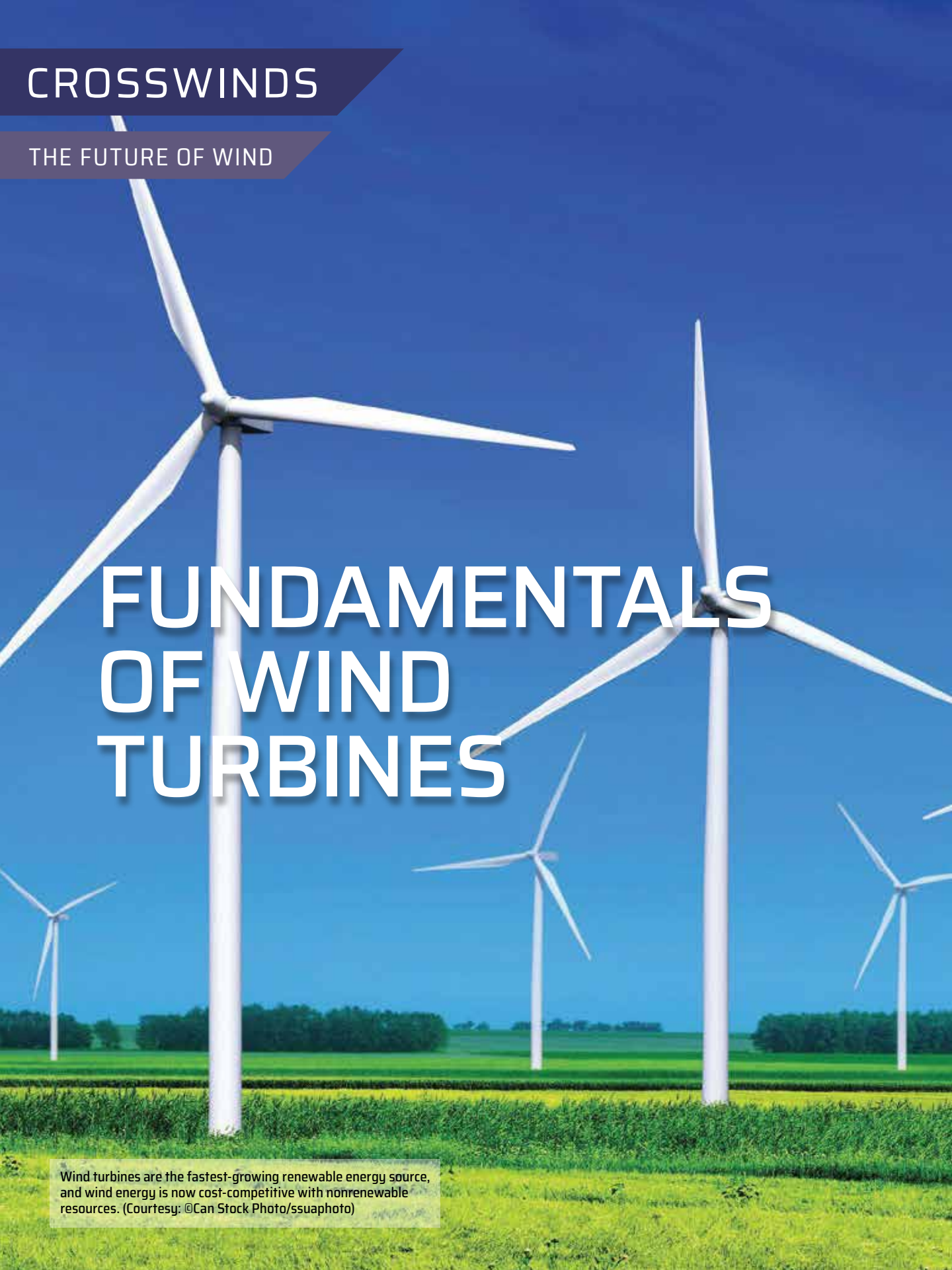
"China, the U.S., and Brazil continued to lead the way in this ratings segment, with 91 percent of capacity orders coming from those three countries," Lewandowski said. "Vestas, SEwind, Mingyang, Goldwind, and DEC compiled orders for more than 1 GW in this ratings segment."

Turbine pricing increased in several markets due to strong demand and larger, newer, more expensive models hitting the market.

"Pricing in the U.S. and China increased due to strong demand, as order books continue to fill up in preparation for 2020 installations," Lewandowski said. "Turbine prices in India have remained unchanged QoQ as developers push back against aggressive auction price ceilings set by the government, however the U.S. dollar has gained 4 percent in value against the Indian rupee since July 2019. This makes Indian turbine prices lower in USD. Newer models in the market and demand for larger turbines in Brazil caused pricing quotes to rise."

MORE INFO woodmac.com

FUNDAMENTALS OF WIND TURBINES



Wind turbines are the fastest-growing renewable energy source, and wind energy is now cost-competitive with nonrenewable resources. (Courtesy: ©Can Stock Photo/ssuaphoto)

Global capacity has grown continuously since 2001, including a 9-percent increase in 2018.

By JANE MARIE ANDREW

The rising concerns over climate change, environmental pollution, and energy security have increased interest in developing renewable energy. We are seeing an unparalleled enthusiasm, demand, and growth in renewable energy production, wind energy being at the forefront. Wind energy is expanding both onshore and offshore with bigger, more powerful turbines, creating new demands and markets.

The global capacity for generating power from wind energy has grown continuously since 2001, reaching 591 GW in 2018 (9-percent growth compared to 2017), according to the Global Wind Energy Council [1].

WIND-PHYSICS FUNDAMENTALS

Wind arises from processes driven by solar energy. The sun's energy creates temperature differences that drive air circulation. Hot air rises, reducing the local atmospheric pressure; nearby cooler air flows into this region of lower pressure; this air flow is wind.

Wind is shaped by both global and local forces. Global patterns are in part the result of the Coriolis force, which arises from the Earth's rotation. As cool air flows from higher to lower pressure areas, it is deflected by the Coriolis force; the direction of deflection depends on latitude. As a result, different regions of Earth have different prevailing wind directions.

At the other end of the spectrum, local geographical features can have specific effects. One such effect, familiar to anyone living near the ocean, is the land breeze. At night, the water is warm relative to the land, so air is warmed over the water and rises; the resulting low pressure draws cool air from land out to sea: the land breeze.

Although there may be a prevailing wind direction, it is not the only wind direction. Both direction and speed are highly variable with geographical location, season, height above the surface, and time of day. Understanding this variability is key to siting wind-power generation, because higher wind speeds mean higher duty cycles (i.e., longer periods of active power generation). It is necessary to measure the characteristics of the wind in great detail, including how often winds of certain speeds occur (see Figure 1) and how the surrounding terrain affects the stability of air flow.

A stable flow with a consistent speed is important for both generating efficiency and structural integrity. Variability leads to wind shear and wake forces. Wind shear is a function of wind speed, which increases with height above the surface. Thus, the shear forces on the rotor blade are greater when it is in the top position.

EQUATIONS FOR WIND TURBINES: WIND SHEAR

An important consideration for turbine siting and operation is wind shear when the blade is at the top position. Wind shear is calculated as:

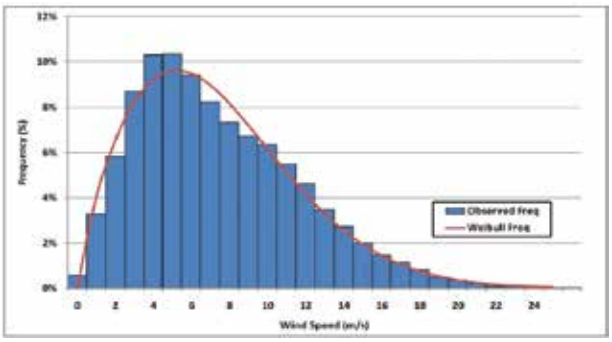


Figure 1: Plot of the frequency of occurrence of different wind speeds over a period of a year. (Courtesy: Sentient Science Corp.)

$$V = V_{ref} \ln\left(\frac{H}{H_0}\right) / \ln\left(\frac{H_{ref}}{H_0}\right)$$

V — Wind speed at height H above ground level.
V_{ref} — Reference speed.
H_{ref} — Reference height.
H — Height above ground level for the desired velocity, V.
H_0 — Roughness length in the current wind direction.

EQUATIONS FOR WIND TURBINES: TURBINE POWER

The energy contained in a mass, m, of moving air with velocity v is:

$$E = \frac{1}{2}mv^2.$$

The mass flow rate of moving air with a density r through a cross-section area A is:

$$m = \rho v A.$$

The power contained in a flowing mass of air through area A is:

$$P = \frac{dE}{dt} = \frac{1}{2}mv^2 = \frac{1}{2}\rho v^3 A.$$

The power extracted by blades of diameter d is:

$$P = \frac{\pi}{8} c_p \rho v^3 d^2,$$

where the power coefficient c_p has a theoretical limit of approximately 0.6; this is referred to as the Betz limit, which defines the maximum amount of wind kinetic energy that can be converted to kinetic energy.

Wake forces are created because the wind slows down and becomes turbulent as it passes the turbine blades. This is why turbines are widely spaced, usually five to nine rotor diameters in the direction of the prevailing wind and three to five rotor diameters in the perpendicular direction.

Wind speed also changes as a result of turbulence, which can be caused by nearby rough terrain, including trees and buildings; these can cause wind speed to vary greatly even within several hundred yards or meters. This effect, called turbulence, decreases efficiency and causes fatigue loading.

WIND POWER FUNDAMENTALS

Energy is captured from wind through the phenomenon of lift—the same phenomenon that allows birds and airplanes to fly. (Turbine blades are, in essence, captive wings.) The lift generated as wind passes over the blade causes it to move, thereby rotating the main shaft. The rotation is transmitted through a gearbox to a generator, which converts it into electricity. The magnitudes of the lift and drag on the turbine blade are dependent on the angle of attack between the apparent wind direction and the chord line of the blade.

Several different factors influence the power output of a wind turbine. Among other factors, wind speed and rotor diameter are the two primary parameters (see Equations for wind turbines).

- Turbine power increases with the square of blade length. For example, increasing the rotor diameter from 262 feet (80 meters) to 394 feet (120 meters) allows power to increase from 2 MW to 5 MW (a factor of 2.5).
- Turbine power increases with the cube of wind velocity. For example, a turbine at a site with an average wind speed of 16 mph would produce 50 percent more electricity than the same turbine at a site with average wind speeds of 14 mph.

These two fundamental physical relationships are behind the drive to scale up the physical size of turbines. A larger rotor diameter allows a single turbine to generate more electricity, providing better return on installation cost. And because wind speed and consistency both increase with height, taller turbines produce a higher and more consistent supply of electricity.

A given design operates with a range of wind speeds. Below the cut-in wind speed, the turbine cannot produce power because the wind does not transmit enough energy to overcome the friction in the drivetrain. At the rated output wind speed, the turbine produces its peak power (its rated power). At the cut-out wind speed, the turbine must be stopped to prevent damage. A typical power profile for wind speed is shown in Figure 2.

In addition to an operating range, an installed turbine has a capacity factor that reflects its actual power generation. The capacity factor is the annual average of power generated divided by the rated peak power. For example, if a turbine rated at 5 MW produces power at an average of 2 MW, then its capacity factor is 40 percent. In general, a higher capacity factor is preferred, although it may not be advantageous economically. For instance, in a windy location, it will be advantageous to use a large-size generator with the same rotor diameter. This would tend to lower the capacity factor, but it will lead to substantially larger annual production.

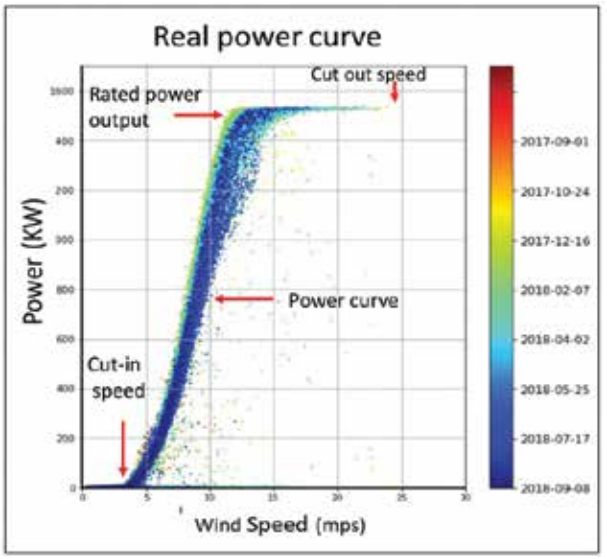


Figure 2: Profile of power output from a wind turbine over a year. (Courtesy: Sentient Science Corp.)

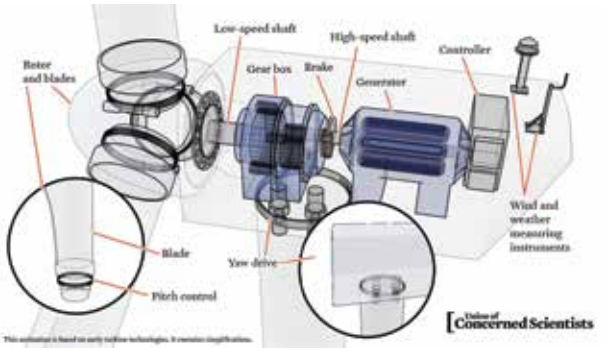


Figure 3. Simplified view of components of an upwind-facing, horizontal-axis wind turbine with a gearbox drive. An animation is available. [2]. (Courtesy: Union of Concerned Scientists, www.ucsusa.org)

WIND-TURBINE TECHNOLOGY

Turbines come in several general categories based on orientation and drivetrain type.

The turbine blades can be oriented around either a vertical or horizontal axis. An advantage of the vertical axis is that blades do not have to be mechanically reoriented when the wind direction changes. Horizontal-axis turbines also come in two general designs. In a downwind design, the blades face away from the incoming wind; in an upwind design, the blades face into the wind (see Figure 3). More than 90 percent of currently installed turbines are of the upwind type, as this design does not create wind shade behind the tower.

For the drivetrain, in a gearbox-drive design, a gearbox is used to increase the speed transmitted from the rotors to the generator. In a direct-drive design, the speed is transmitted directly to an annular generator. Aside from the gear-

AD INDEX

box, the components are generally similar; however, in a direct-drive turbine, the generator is much bigger because it must rotate at the same speed as the turbine blades.

The wind-turbine components that experience friction and wear and require lubrication are the following:

- Pitch bearing (grease).
- Main shaft bearing (grease).
- Gearbox if any (oil).
- Yaw drive (grease).
- Generator bearing (grease).

The pitch drive is used to adjust the angle of the blades. This adjustment is made for two reasons: 1) to capture maximum power from winds below the rated output wind speed or 2) to slow the blades for safe operation at winds above the rated speed. The yaw drive moves the blade and housing assembly (the nacelle) to the optimum direction in relation to the wind. An animation prepared by the Union of Concerned Scientists is helpful in visualizing the action of these drives [2].

Figure 4 shows a typical three-stage wind turbine gearbox. A planetary stage (bottom left) transfers the torque first to a low-speed intermediate stage (bottom right) and then to a high-speed intermediate stage (middle), which drives a high-speed stage (top) that feeds the generator. Such a design might, for example, convert 14 rpm input from the rotors into 1,500 rpm to the generator; the exact conversion of course depends on the gear ratio. Different bearing types are used in these various components.

Some technical differences should be noted between land-based and offshore turbines. As noted previously, offshore installations account for more than 3 percent of global capacity. Offshore construction presents different challenges, the most obvious being how the structure is anchored. The strategy differs depending on the water depth. For depths less than about 100 feet (30 meters), monopile construction is used. For transitional waters (100-200 feet or 30-60 meters), a cross-braced "jacket" foundation is used. For deeper waters, prototype floating platforms are being tested. The transformer design also is different for different water depths, and in general, offshore installations are moving from gearbox to direct-drive designs.

Another significant difference is size. Without the need to limit noise or accommodate terrain-induced turbulence, designers can pursue truly giant scales. GE has built an offshore design rated at 12 MW, significantly higher than the 2017 average of about 2.3 MW. It is indeed a giant: The rotor diameter is on the scale of the towers of the Golden Gate Bridge, and the surface area of the blade sweep is equivalent to seven American football fields. In this design, the torque is transmitted directly to the generator. Why build such giants? In addition to raising power output, large turbine reduce installation cost. Installing one 12-MW turbine is cheaper than installing six 2-MW ones; thus the final cost per megawatt is lower. For these reasons, and because of the abundance of offshore wind resources, the industry is moving to an emphasis on offshore wind power.

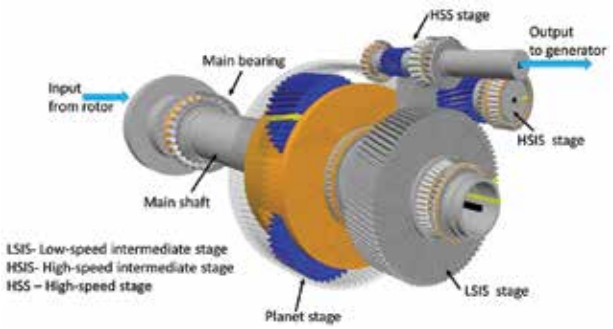


Figure 4: Power flow diagram of a typical three-stage wind turbine gearbox. The low-speed input from the rotors (far left) is converted into high-speed torque at the output shaft (HSS) to feed the generator (top right). (Courtesy: Sentient Science Corp.)

SUMMARY

Wind turbines are the fastest-growing renewable energy source, and wind energy is now cost-competitive with non-renewable resources. Growth in generating capacity is concentrated in five to 10 states, notably Texas. Five companies lead in the installation market. The field of turbine manufacturers is crowded, but GE Renewable Energy and Vestas are clear leaders. Increasingly, capacity is being purchased by entities other than utilities, and offshore installations are becoming more attractive and viable.

In terms of technology, turbine design focuses on optimizing power output by focusing on two key parameters: blade length and average wind speed. The latter is affected by surface terrain and varies spatially, directionally and seasonally. The effectiveness of a particular installation is quantified by a capacity factor: the ratio of actual annual energy output to the theoretical maximum output. A number of basic designs are in use, but most commercial installations use a horizontal axis, upwind-facing design. Turbines are becoming ever larger, in both physical size and generating capacity, in order to capture more stable winds and to maximize return on installation costs.

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[1] Global Wind Report 2018, by Global Wind Energy Council. Available at https://gwec.net/global-wind-report-2018/.

[2] "How Wind Energy Works," by the Union of Concerned Scientists. Available at www.ucsusa.org/clean-energy/renewable-energy/how-wind-energy-works.

ABOUT THE AUTHOR

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