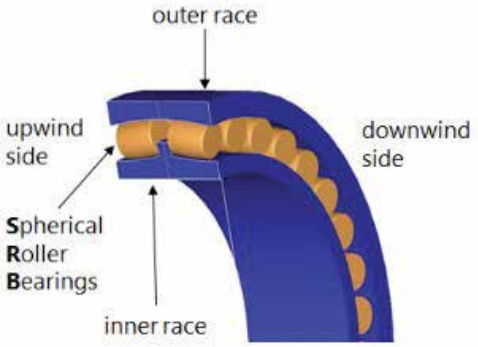
DATA-DRIVEN MAIN BEARING MAINTENANCE STRATEGIES TO REDUCE UNPLANNED MAINTENANCE COSTS

By Becki Meadows and Jason Shapiro



All images, graphs, and figures are courtesy of Romax Technology.

Figure 1: Main bearing failures predominantly occur on three-point mount turbine designs, which utilize a single double-row spherical roller bearing.

Main bearing failures can wreak havoc on a wind farm's annual operating budget. Operators are experiencing high numbers of main bearing failures resulting in unplanned operating costs. Reference data from seven sites over four years shows that annual failure rates of 3-6 percent are not unusual. As bearings age and damage accumulates, that rate of failure is expected to increase.

Although replacement costs can be as high as that of a gearbox, main bearings are usually not maintained with the same rigor. Effective maintenance and life extension strategies exist that can be easily incorporated into a wind farm's overall maintenance plan to reduce downtime and unexpected expenses.

ROOT CAUSE ANALYSIS FINDINGS

The majority of main bearing failures are occurring on three-point mount turbine designs. This arrangement has one main bearing to support rotor weight and thrust and two gearbox mounts that support rotor weight, bending loads, and torque. Double row spherical roller bearings (DSRBs) are selected for the main bearing due to cost, their ability to handle a large amount of radial load (supporting the weight of the rotor), and their self-aligning capability — a requirement in this arrangement (see Figure 1).

The drawback in the three-point design is that the thrust loads are often too high for DSRBs. This results in a ratio of an axial-to-radial load that is too high and leads to undesirable roller skewing and sliding as the bearing rotates. The bearing already operates under poor lubrication conditions, as the rolling speeds are very slow, making it difficult to generate the needed lubricant film thickness in the loaded zone between rollers and raceways. The skewing and sliding exacerbates the issue, and the end result is micropitting, which generates debris. The debris is trapped in the bearing and causes three body abrasions and surface-initiated spalling, which generates more debris and an accelerated failure cycle (see Figure 2).

Romax InSight has performed numerous root cause analyses on this three-point mount turbine design, which have confirmed the primary mode of failure to be surface-initiated fatigue (see Figure 3):

- Metallurgical, measurement, and visual investigation of the bearings have ruled out material, assembly, and heat treatment issues
- Teardown and inspection of the bearings confirm the wear is consistent with excessive axial-to-radial load ratios.

CONDITION-BASED MAINTENANCE TOOLS

Many wind farm owners are only aware of main bearing failures after SCADA temperature alarms alert them to the issue, which usually corresponds to the final stages of bearing deterioration. Figure 4 provides a case study where advanced vibration fault detection algorithms provided more than one year's warning on a main bearing failure when the first debris dents appeared on the inner race. Temperature warnings often occur at a very late stage, even when using advanced algorithms to correct for environmental fluctuations.

Combining SCADA temperature data with vibration data and grease

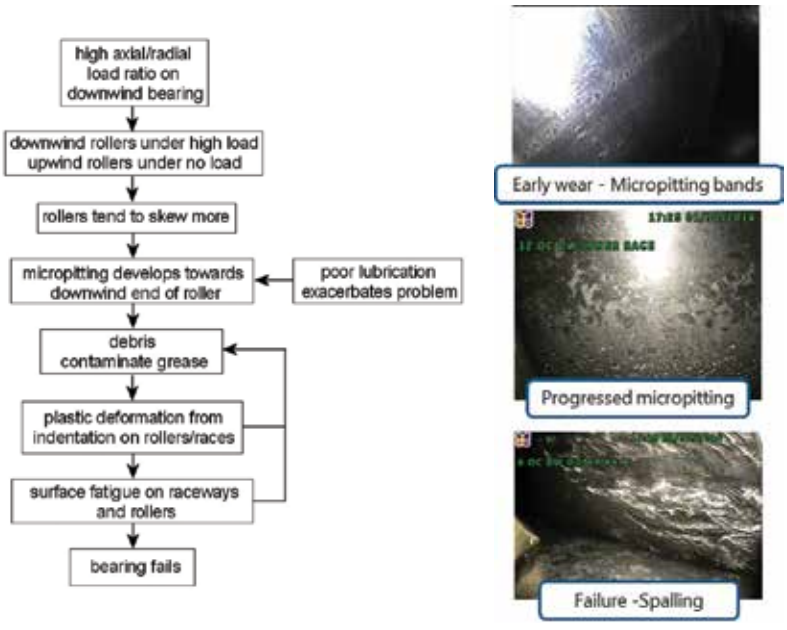


Figure 2: Main bearing failure cycle of roller and raceway surfaces, accelerated by trapped debris.

analysis gives owners a more comprehensive toolset to detect main bearing damage and degrading lubrication conditions early on. With this information, repair costs can be better forecasted, prioritized, and ultimately reduced through minimizing downtime and sharing the cost of crane mobilization with other planned repairs (see Figures 5 and 6).

Additional cost savings exist by preventing secondary damage to the gearbox that can occur when running a main bearing to failure. The gearbox is mounted on rubber mounts that principally react the thrust, but, together with the main bearing, also support rotor-bending moments. When the main bearing is run to failure, the internal clearance is increased (due to wear) and can eventually result in the thrust load being transferred to the gearbox. The planet carrier bearings take this thrust load on the bearing shoulder (outside its design intent), and the carrier may

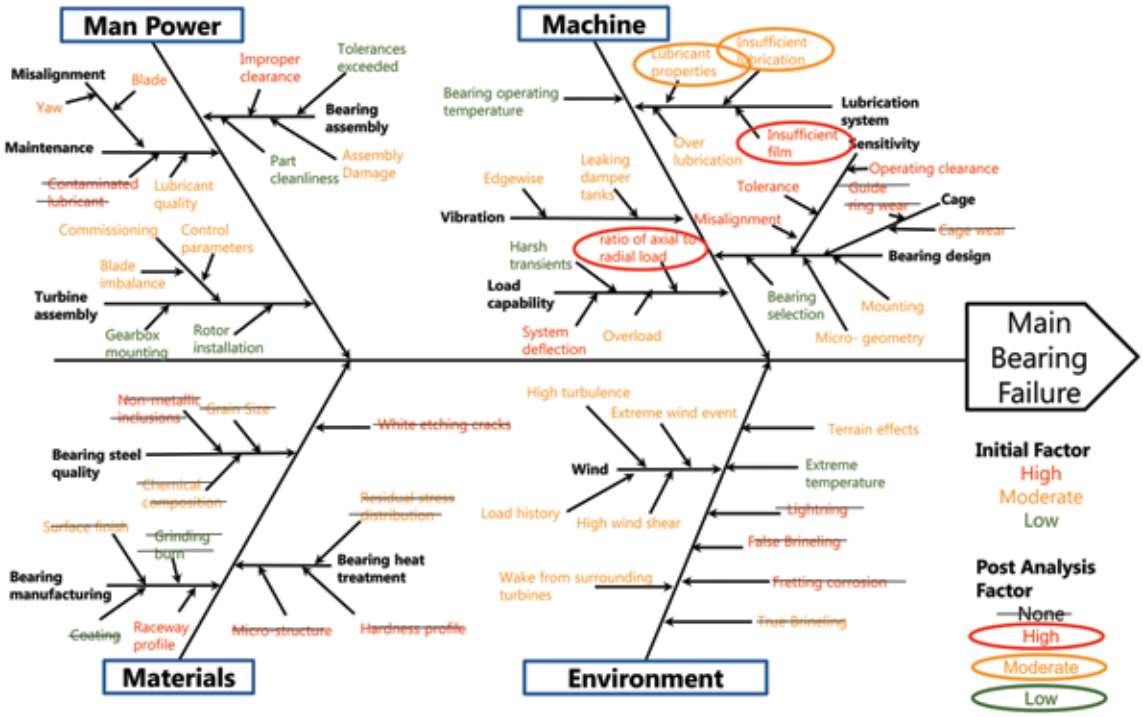


Figure 3: Fishbone diagram reduces in-root causes to confirm that the likely cause of failure is excessive axial-to-radial load ratios causing load to be carried exclusively by downwind row.

also become cocked to the ring gear, affecting planetary alignment.

LIFE EXTENSION STRATEGIES

While identifying main bearing damage early reduces the costs associated with unscheduled maintenance, the service life of the damaged component is still finite. To address this, a number of strategies exist for extending the life of damaged main bearings, including grease purging, manual grease removal, and grease flushing. The objective is to remove the old, hardened, and contaminated grease, which can cause surface fatigue on the raceways of the bearing and the rollers and lead to accelerated failure. Grease flushing is distinct to the industry norm, where only a partial volume of the grease

Figure 4: Romax InSight Fleet Monitor™ software tracking main bearing damage provides over a year's leadtime on the failure using advanced algorithms applied to the raw vibration data feed.

is manually removed or pushed through by purging for an inadequate clean. A significant life extension requires that almost all the grease must be removed.

Romax InSight has developed a process to assess and extend main bearing life. Developed in-house, this process allows the majority of the grease from within the bearing to be flushed. The bearing is then repacked with fresh grease and can continue operation as normal. This process has proven to reduce the operating temperature of main bearings with severe wear by up to 20°C, as well as reducing the number of large and small density particles to that of fresh grease, which can vastly improve the remaining useful life of a bearing.

EXTENDING LIFE FOR SEVERELY DAMAGED BEARINGS

In cases of severely damaged bearings, flushing may be utilized as a tool to allow the operator to continue bearing operation until a replacement can be made. An operational extension of three to six months can be achieved for cases where the bearing was severely damaged prior to flushing. In some cases, 12 months or more have been observed. Figure 7 summarizes a recent case study where an owner had two damaged main bearings in a farm with multi-megawatt wind turbines. Wind Turbine Generator B (WTG-B) was flushed three months after vibration and inspection confirmed damage. Wind Turbine Generator C (WTG-C) went through multiple grease purges (no flushing) to combat turbine shutdown due to high temperature alarms. Recent

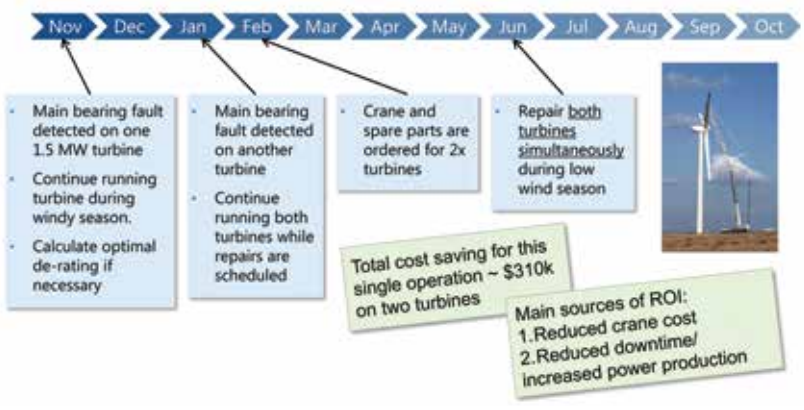
WT	Vibration	Inspection	Grease	Temperature	Recommendation	Priority Rank
T_A	2: Inner race damage trend not yet rising	Not inspected	2: Water, Fe, Si at warning levels	1: Comparable to fleet average	Inspect and consider flushing main bearing	Medium
T_B	2: Inner race damage trend not yet rising	Not inspected	N/A	1: Comparable to fleet average	Inspect and collect grease sample from between rollers	Low
T_C	3: Inner race damage trend rising	Not inspected	4: Fe, Si and Cu above alarm level	1: Comparable to fleet average	Inspect and consider flushing main bearing	High
T_D	4: Inner race damage	3: Damage observed during inspection	4: Fe and Cu above alarm level	4: Above fleet average	Inspect and consider flushing bearing to extend life	High
T_E	3: Outer race damage and trend rising	Not inspected	N/A	1: Comparable to fleet average	Inspect and collect grease sample from between rollers	Medium
T_F	1: Normal	1: Normal	3: Fe and Si above alarm level	1: Comparable to fleet average	Inspect and consider flushing main bearing	High

Ranking Key

Notification Other	Normal	Initial Indication	Developing Issue	Progressed Issue	Critical

Figure 5: (Above) Main bearing data-driven inspections; combining vibration, SCADA, and grease analysis data allows better forecasting and prioritization of main bearing maintenance and repairs.

Figure 6: (Below) Early detection of main bearing damage using condition monitoring results in significant cost savings through scheduling simultaneous repairs.



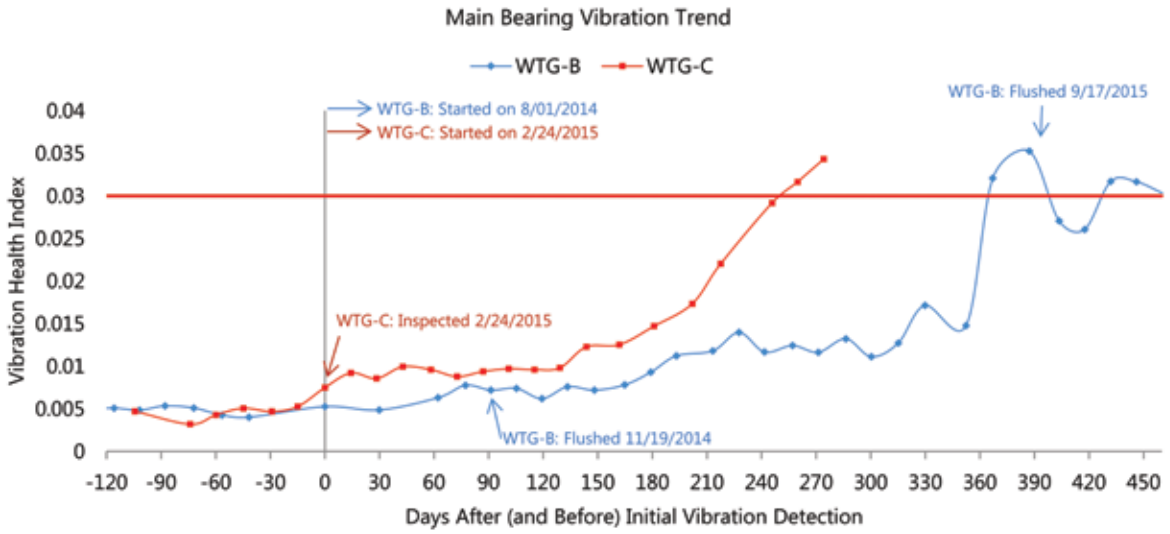


Figure 7: In cases of severely damaged main bearings, flushing may be utilized as a tool to extend the life of the bearing in order to optimize the time of replacement.

inspections classified both main bearings as having severe damage, but the turbine that wasn't flushed progressed to failure at a faster rate.

Close temperature and vibration monitoring is required, as a severely damaged bearing may progress to functional failure and require shutdown. Additionally, running a spalled bearing can result in subsequent gearbox damage and needs to be monitored closely to avoid impact to planet carrier bearings.

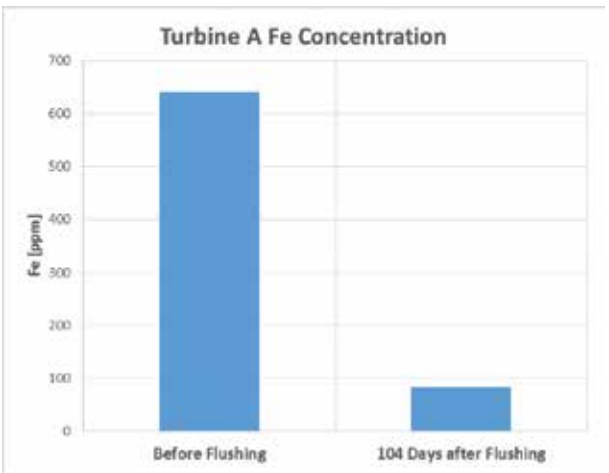
PREVENTATIVE MAINTENANCE FLUSHING

Some owners have taken the proactive initiative of flushing bearings as part of preventative maintenance strategy to remove old and contaminated grease from non-damaged bearings. Over time, even healthy main bearings will accumulate foreign contaminates and degraded grease, which reduces the bearing service life. Auto-lubrication units installed on main bearings help by providing a fresh supply of grease, but these systems are unable to remove contaminates and degraded grease from the bearing. Romax InSight has observed significant reductions in contamination levels in main bearings that have been flushed early (see Figure 8).

PREDICTIVE-BASED MAINTENANCE DATA

Early detection of main bearing damage and flushing can provide wind farm owners and operators with a more comprehensive toolset to manage main bearing failures. However, a piece of the puzzle is still missing in terms of forecasting the time to failure.

Figure 8: Benefits of preventative maintenance flushing; 104 days post-flushing iron content is reduced by 87 percent.



To address this requirement, Romax InSight has developed a database of component failures to provide wind farm owners with an estimate of remaining useful life once vibration and inspections have confirmed damage. RomaxRepair utilizes mathematical models and empirical data along with engineering experience to forecast the time to failure. After detection and the first evidence of damage is determined, the remaining production hours are calculated. Based on the time of year, the production hours are converted to a date range for expected failure to guide an optimized schedule for repairs.

Figure 9 shows the RomaxRepair estimates for WTG-B and WTG-C from the aforementioned case study. Turbine B lasted 137 days longer than 75 percent of the main bearings in the database. Turbine C that was not flushed will be replaced with average life after initial signs of failure.

Figure 9: RomaxRepair estimates the remaining useful life once main bearing damage has been detected and confirmed.

CONCLUSION

Wind farm owners and operators will inevitably face main bearing failures. Unplanned labor, unscheduled downtime, and additional crane mobilization fees are all factors that can be managed. Efficient analysis of SCADA and CMS data that result in data-driven inspections can be an invaluable way to improve maintenance planning and, when combined with life extension strategies and remaining useful life estimates, equips the wind farm owner with a powerful toolset for minimizing downtime and saving on O&M expenditure.

DROPPED OBJECT PREVENTION: TOOLS WITH ENGINEERED ATTACHMENT POINTS CAN INCREASE SAFETY AND PRODUCTIVITY

By John Tremblay

Snap-On Industrial

GE 1.5 hub hatch tool with engineered attachment point

The wind power industry, along with the Occupational Safety and Health Administration (OSHA), has recognized dropped objects as a significant safety and productivity concern. According to the American Wind Energy Association (AWEA), dropped objects continue to lead the near misses reported by many wind energy companies, so much so that the association's first safety awareness month in October 2015 was entitled "Prevention of Dropped Objects." As the market matures and continues to establish policy and behavioral standards, programs and training opportunities that address this topic are emerging.

While there are federally mandated guidelines for securing people who work on surfaces 4 feet or higher from the ground, there are no such requirements for securing tools. While most organizations recognize the need to prevent tools from falling, identifying and implementing effective solutions has been challenging for a number of reasons. Fortunately, new methodologies are available that not only better secure tools while working at great heights, but also maintain the tool's full functionality for increased safety and productivity.

OLD CHALLENGES, NEW IDEAS

Tethered tools are not a new concept. Tethering devices come in many shapes and sizes, but many fall short for one reason or another. Some mount in a way that limits the full use of the tool and are difficult to handle, while some technicians view them as obstructions to productivity. Others work with only a portion of the tools, leaving some unsecured. With that said, the most common complaint related to tethered devices is that they inhibit the functionality of the tool. A tool can be tethered, but if the system inhibits safe and proper use, then the objective of a safer working environment is not reached.

ENGINEERED ATTACHMENT POINTS

New technologies for drop prevention have emerged that focus on maintaining or enhancing a tool's functionality. An important development is that these new tethering systems are designed in conjunction with the tool and not looked at as

an afterthought. Developing system components independently is what ultimately compromises functionality and inhibits program implementation. Engineered attachment points must consider a tool's design and function in order to maintain or improve use when tethered. Rigorous drop testing to certify the design of attachment points should also be in place to ensure safety. Fortunately, there are new innovative offerings that satisfy these criteria. Some examples of such innovation include:

- Locking pins: Square drive tools and accessories are designed and manufactured with spring-loaded lock pins in square drives. The lock pin engages with side lock holes drilled in sockets, extensions, and adaptors, ensuring positive retention. A pin-release tool is used to separate components in the system. This method is preferred over using quick-release tools because a quick-release button or collar can be activated inadvertently, causing the drive tools to separate and become dangerous dropped objects.
- Rotating tabs: Screwdrivers are fitted with stainless steel tabs that rotate freely 360 degrees so that lanyards do not tangle around the user's hand or the screwdriver handle. This method also leaves all of the gripping surfaces available so that the tool can be used ergonomically.
- Strategic location: Rather than taping a ring on the handle of a plier where it will obstruct the user, engineered attachment points are located away from the gripping surfaces, allowing full functionality.
- Turnkey toolkits: Complete toolkits with engineered attachment points and asset management systems are now available as one line item solutions. They arrive fully assembled and ready for implementation. This type of program reduces the cost of the acquisition while improving safety and productivity and reducing the risk of foreign object damage (FOD) or foreign material exclusion (FME).

Snap-On Industrial

Soft bag toolkit with engineered attachment points and inventory management system

Snap-On Industrial

Hard case toolkit with engineered attachment points and inventory management system

TRAINING

As with any change, implementing an effective dropped object prevention program requires a culture shift. Training standards are being developed by organizations like the National Coalition of Certification Centers (NC3). More information on NC3 can be found on its website at www.nc3.net. Also, the first dropped object prevention certification program of its kind was offered last year by Iowa Lakes Community College (ILCC). More information on this initiative can be found on the college's website at www.iowalakes.edu.

For more information, go to www.snapon.com/industrial.

GENERATION WIND COMES TO NEW ORLEANS

By Tim Morris

Last spring, the United States Department of Energy (DOE) set an ambitious goal that, if achieved, would usher in a new era in American energy. The DOE's target: to generate 20 percent of the country's electricity with wind energy by 2030.

Today, the U.S. is on track to meet or exceed that target. In 2015, wind was America's largest source of new electric generating capacity, representing 35 percent of all new energy to come online. That's more than solar or natural gas. Overall, there's now enough wind energy in the U.S. to power 19 million American homes, and the U.S. produced more electricity from wind than any other country in 2015.

At the state level, progress is just as impressive. Last year, Iowa became the first state to generate more than 30 percent of its electricity using wind. Overall, wind now reliably supplies at least 10 percent of the electricity in a dozen states.

Reaching these milestones means not only cleaner energy, but significant economic activity as well. More than $128 billion has been invested in the U.S. economy over the last 10 years from the construction of new wind projects, while the country's fastest growing job is now wind turbine technician.

Cost declines of 66 percent in the last six years combined with the long-term policy stability achieved with December 2015's five-year extension of the Production Tax Credit mean wind energy is poised for even greater growth in the years to come.

As the U.S. wind industry has matured and gets ready to move to the next level, we at the American Wind Energy Association (AWEA) realized it was time for the AWEA Windpower 2016 Conference & Exhibition to do the same.

After gathering feedback from AWEA members on how to best meet the evolving industry needs brought on by increasing demand, we decided that Windpower — the largest annual wind energy conference in North America — needed some adjustments.

One of the biggest changes is to the conference's education program.

With "Generation Wind" as 2016's theme, we crafted a program that encompasses the growing demand for wind energy, and for the first time, made it available to all Windpower attendees. We've quadrupled the number of sessions, and we're placing them all on the show floor. Every attendee and exhibitor alike can benefit from the 99 presentations and sessions scheduled across five main stations throughout the exhibit hall.

For a better understanding of how the industry's leading experts are pushing for a new wave of global wind

development, visit the Power Station where attendees will hear about new commercial opportunities, market expansion, and lessons learned and applied. Owners and operators looking for management strategies to address current and future operational life-cycle issues will find everything they need at the Operations Station powered by UpWind Solutions.

At the Technology Station powered by GE Renewable Energy, leaders in business, academia, and government are coming together for a discussion on ways to advance innovations in wind technologies that could fundamentally change the industry. The Project Development Station powered by AWS Truepower is where attendees can examine every step involved in developing a wind project, from siting and wildlife to transmission, integration, and forecasting.

Returning from last year's conference, the Thought Leader Theater powered by Mortenson will be dedicated to defining the future of wind with more than 14 hours of forward-thinking and thought-provoking content.

Continuing to build a better future is a key aspect for Windpower's theme, Generation Wind, because today's youth are tomorrow's leaders. The next generation of wind leaders is more attune to the positive environmental impacts of wind and the ways in which it can strengthen the economy.

At Windpower 2016, junior high school students will put their talents to use at the National KidWind Challenge. Teams of undergraduates will also attempt to use skills across several disciplines to research, site, market, and build hypothetical wind projects during the DOE's Collegiate Wind Competition. Local area schools will also have the opportunity to learn about wind energy during the conference's "Public Day."

Perhaps most notably, veterans will have the opportunity to connect with up-and-coming leaders during the Emerging Leaders Program. This is a chance for wind's next generation to absorb wisdom from the old guard, while also providing their more experienced counterparts with new perspectives and fresh ideas.

See what Generation Wind is all about at the AWEA Windpower 2016 Conference & Exhibition May 23-26 in New Orleans. American wind power has turned a corner, and you'll be able to get all the information you need to make sure you stay ahead of the curve.

For more information,
go to www.windpowerexpo.org.

2016 COMPLETE WINDPOWER BOOTH LISTINGS

3M Renewable Energy Div 5119
3S Lift 3529
ABB Inc. 3439
Acciona Energy 2138
Adolf Thies GmbH & Co. KG 5539
Aercoustics 1640
AeroTorque Corporation 1922
Aggreko, LLC 5412
Aimco 2349
Airway Services, Inc. 4249
AKE Safety Equipment 1825
Alcoa Fastening Systems & Rings 1334
ALL Erection & Crane Rental Corp 4044
Alliance for Clean Energy New York, Inc. - ACENY 5449
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AL-PRO Wind Energy Consulting Canada Inc. 3654
Amec Foster Wheeler 2123
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American Wind Wildlife Institute 1647
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Atlas Copco Tools & Assembly Systems 2423
ATS Projects 1117
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Avid Controls, Inc. 2729
AWEA New Product and Innovation Pavilion 2217
AWEA Regional Partners 5449
AWEA Small Business Pavilion 2317
AWS Truepower, LLC 4823
Axis Renewable Group, Inc. 2723
Aztec Bolting Services Inc. 1329
Bachmann electronic GmbH 4813
Bancroft Contracting Corp 3719
Barr Engineering Co. 2529
BayWa r.e. 4629
Baze Technology AS 2916
BDI 2143
Beckhoff Automation ApS 4738
Beka Max of America Inc. 3049
Bently Nevada 1846
BERDAN-TECH LLC 2448
BGB Technology Inc 3826
Bijur Delimon International 4047
BJA Magnetics 3122
BladeEdge 2719
BNSF Logistics, LLC 5213
Breeze 3755
Bruel & Kjaer Vibro 4638
BS Rotor Technic USA 2818
BSEE 3754, 3756
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Bureau of Ocean Energy Management (BOEM) 3756
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BWS, LLC 4049
C Speed 2221
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California Wind Energy Association (CalWEA) 5449
Campbell Scientific, Inc. 1217
CAN Equipment Sales (CAN-USA INC.) 3412
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CENTA Corporation 2849
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DEX 3014
DHHI Germany GmbH 1938
Dialight Corporation 2619
DIgSILENT Americas LLC 5349
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DNV GL 3839
Double-k Consulting 3655
Drake Lighting, Inc. 5315
DTBird & DTBat 2047
DTU Wind Energy 4543
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Electrical Consultants, Inc. 4447
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EMA Electromechanics LLC 5129
Embassy of Spain, Trade Commission - ICEX 2047
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enerG Magazine 3554
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Enviropeel USA 1712
Envision Energy USA 1421
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Epsilon Associates, Inc. 4613
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EverVest 2513
eWind Solutions 3355
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Fagen Inc. 1639
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FieldSystems 1208
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FT Technologies 4938
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Fusion Inc 3113
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GEV Wind Power US 3855
Gexpro Services 3519
Global Lightning Protection Services A/S 4439
GlobalTech Motor & Controls, Inc. 3214
Goldwind Americas 2825
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Gradient Lens Corporation 3312
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Hanes Supply, Inc. 1308
HARTING, Inc. of North America 1836
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IronWolf Manufacturing, LLC 2756
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Luminate, LLC 5112
LZY Technology, Inc. 5319
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Oerlikon Balzers USA Inc.....2449
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Pintsch Bubenzer USA....4038
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