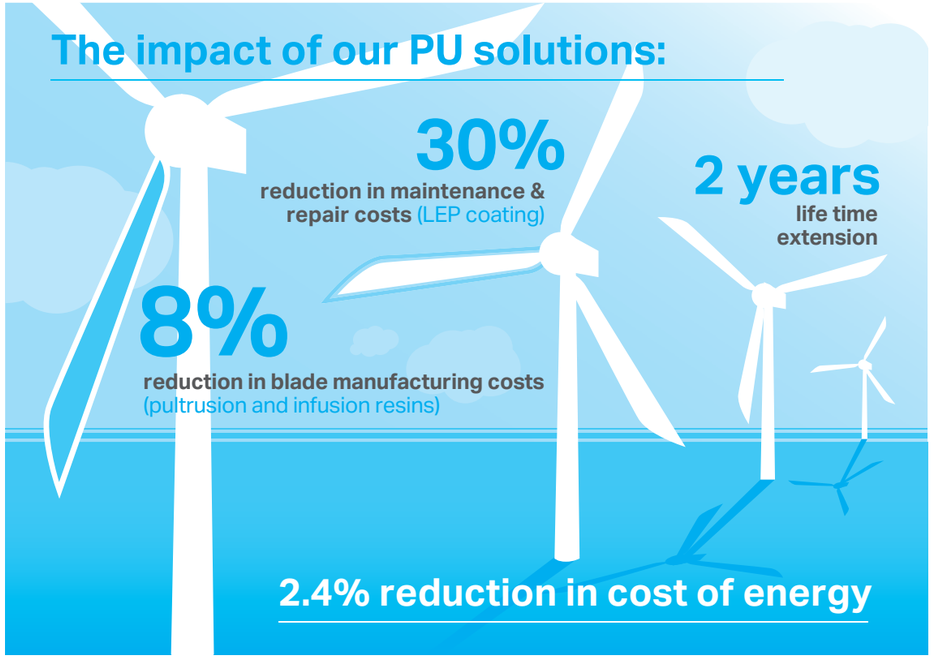
Leveraging advanced polyurethane resins and coatings to develop high-performance wind turbine blades

Dr. Johann Maass
bewind GmbH

Dirk Soontjens
Covestro NV

Ernesto Silva M.
Covestro Deutschland AG
Tailored Urethanes

Thomas Baeker
Covestro Deutschland AG
Coatings & Adhesives



Covestro and bewind translate unique blade material properties into cost savings for wind energy

Covestro has applied its industrial expertise in high-tech polymer materials to develop innovative polyurethane (PU) solutions for wind turbine applications that offer performance benefits and lower blade costs.

To evaluate the impact of our PU solutions for rotor blade applications, Covestro commissioned bewind GmbH, a specialist wind engineering consultancy company, to simulate the costs and benefits of these solutions in terms of production, operational performance, and turbine lifetime. The company evaluated three of our PU products: a pultrusion resin, an infusion resin, and coating raw materials for leading edge protection (LEP). The aim was to quantify the impact of Covestro polyurethane solutions compared to standard alternative products used on a typical offshore wind farm.

The findings indicate that Covestro PU solutions speed up blade part manufacturing, increasing efficiency and reducing production costs. PU blades demand less raw material, and thus reduce the blade weight, which provides significant benefits in the field. The advanced physical properties of the PU resins enable the blades to have high performance and potentially last longer, increasing the energy generated over the course of their service life. The exceptional durability of the LEP coating based on PU raw materials provides outstanding erosion protection, reducing repair frequency and maintenance costs of the blade over its lifetime.

The combination of Covestro high-performance PU resins and coating raw materials represents a break-through innovation with a strong positive impact on wind project economics.

Covestro is one of the world leading polymer companies.

With 2021 sales of EUR 15.9 billion, 50 production sites worldwide, and approximately 17,900 employees, Covestro is among the world's largest polymer companies. Our business activities are focused on the manufacture of high-tech polymer materials and the development of innovative, sustainable solutions to the greatest challenges of our time. Covestro is focussing its efforts on the circular economy, renewable energy is becoming a major driver for the company.

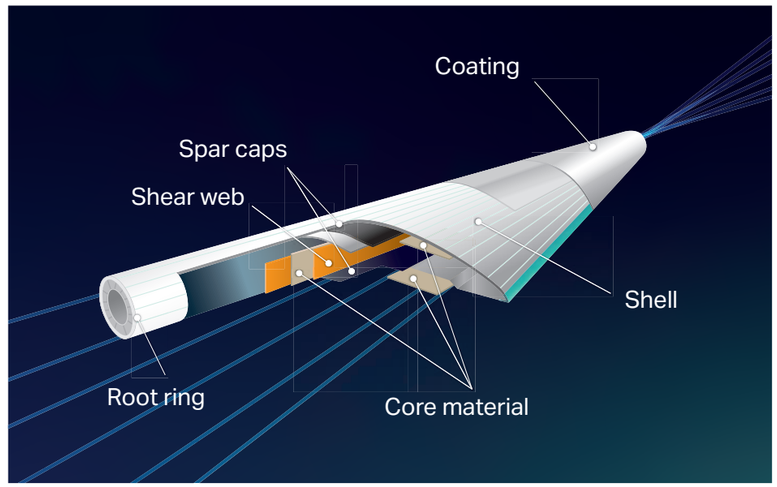
For the wind industry in particular, Covestro is striving for more cost-effective, more sustainable material solutions to support the further expansion of wind energy, and we leverage our global materials and processing expertise for this purpose.

bewind is a specialist wind engineering consultancy with outstanding expertise.

The mission of bewind is to enhance and optimize the product development process of wind turbines through the integration of agile and data-driven methods. The objective is to significantly reduce time to market and improve market fit in fast-developing wind markets. The company has delivered benchmark-setting wind energy solutions for several customers around the globe, using state-of-the-art design tools and processes to optimize engineering solutions and deliver innovative products.

Manufacturing lighter, stronger and cheaper blades more efficiently

Thanks to the low viscosity and short curing time offered by our PU resins, blade manufacturers can reduce production cycles, delivering more blades in less time. This in turn optimizes mold occupation and reduces material and labor costs per blade, which translates directly into savings in the levelized cost of electricity (LCoE). In this case study, Covestro PU solutions reduce total blade manufacturing costs by up to 8% in comparison with a reference scenario.



Typical wind blade design showing infused and pultruded parts.
Coatings are spray- or roller-applied to the outer shell.

Benefits of PU infusion resin

The vacuum infusion process involves driving the resin mixture into a mold containing layers of dry fiber under low pressure, and curing it at high temperature. The simulation presented below in the case study indicates that the superior attributes of the PU infusion resin can lead to production cost reductions of up to 13% for infused parts.

PU infusion offers two key advantages compared to epoxy. Although drying is required prior to PU infusion, involving a process similar to an extended pressure drop test, the low viscosity of the resin (50 mPas for PU vs. 150 mPas for epoxy at 35°C) allows the material to flow easily and fill the mold up to twice as quickly. The curing time of PU resin is shorter than that of epoxy due to its high reactivity at elevated temperatures; 3 hours at 80°C and down to 1 hour at 90°C. By comparison, the curing time of a typical epoxy resin is 6 to 9 hours depending on the system and curing temperature. Even considering the additional drying step required for PU infusion, the overall process time is reduced by an estimated 20% compared to the epoxy resin process.

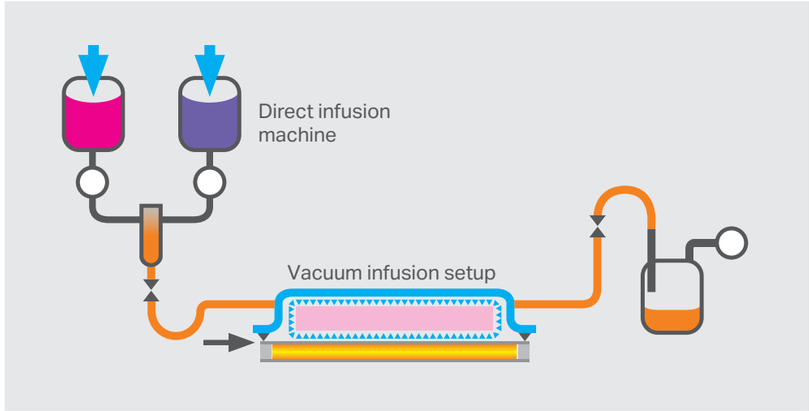
Moreover, the direct infusion process, which is required for PU, allows for a more precise injection into the mold. This minimizes waste and avoids release of volatile organic compounds (VOCs), leading to important health, safety and environmental (HSE) improvements. Precise quantities of the PU components are mixed just prior to injection into the mold, which means that the resin is always freshly mixed and there is no significant variation in viscosity during infusion. The process can be highly automated and traceable, since the degassing, mixing and infusion are all carried out by a single machine. Covestro has worked in partnership with machine manufacturers to optimize the process and accelerate machine developments to make them available to the market.

Benefits of PU pultrusion resin

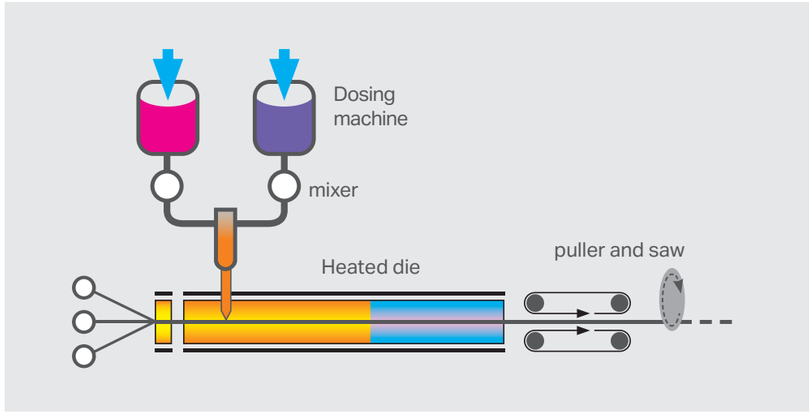
Pultrusion is an automated, continuous manufacturing process used to produce fiber-reinforced polymer (FRP) profiles with constant cross-sections, whereby fiber reinforcements are saturated with resin and channeled into a heated die. Bewind's simulation indicates that PU pultrusion technology can reduce the cost of manufacturing spar caps by up to 14%. The profile exits the die in a solid state.

Due to the low viscosity and fast curing of PU pultrusion resins, the line speed can be up to twice as fast when compared to alternative resins such as vinyl ester or epoxy. To enable the production of parts with the highest requirements, especially regarding stiffness, Covestro has developed PU resins for both glass fiber and carbon fiber pultrusion which offer excellent wetting of fibers and fast curing, enabling pultruders to increase productivity and significantly reduce production costs to fulfill high-volume production requirements.

Furthermore, polyurethane is processed in closed systems which offer high safety in production, and the docile nature of Covestro PU resins allows for a smooth production, even if the pultrusion line has to be stopped temporarily.



a. Direct infusion process minimizes waste, avoids VOC emissions and improves infusion quality.



b. PU pultrusion process allows for increased line speed and high productivity.

The shorter production cycles for both infusion and pultrusion parts generate savings in direct processing costs of around 7%. The lower materials bill generates additional savings so that total cost of blade production can be reduced by up to 8%.

The low viscosity of PU resins compared to epoxy allows for excellent impregnation and denser packing of the fibers which means that less resin and simpler fiber reinforcement layups are needed to achieve the target mechanical properties. This enables lightweight designs with blade weight savings of up to 5% compared to standard epoxy blades.

While the transition from existing blade manufacturing techniques using epoxy or polyester resins to PU resins requires capital investment in new equipment or equipment adaptations, the quicker throughput and efficient use of capacity (e.g., mold occupancy, pultrusion lines speed) provides significant advantages for both existing production plants and for new capacity investments to meet the growing demand for wind energy worldwide.

Increasing energy production in the field

In terms of operational performance, Covestro PU solutions provide two key benefits for the design of wind turbine blades: (i) the mechanical properties of PU resins increase blade reliability, and the potential for lower weight parts reduces static and dynamic loads, (ii) high-performance coatings offer unmatched leading-edge protection (LEP) against erosion, requiring less maintenance and reducing downtime. The combined benefits of these solutions helps maintain a high rate of annual energy production (AEP), extending the blade lifetime by 2 years, and generate significant gains in total energy production over the service life of a wind turbine.

Less maintenance, less downtime, more energy

The low viscosity of Covestro PU resins allows for a denser packing of the fibers, or higher fiber volume content (FVC), which leads to better mechanical performance in terms of strength and stiffness. The matrix dominated properties of PU resins improve fatigue resistance.

Stiffer and thinner spar caps result in less deflection of the blades due to improved geometrical moment of inertia, while allowing designers to fulfil tower clearance load cases. This is particularly important for longer blades which have a greater susceptibility to deflect, requiring them to be positioned further away from the tower to prevent damage or collision.

Blade weight is a key consideration in rotor blade design. PU systems enable the production of parts with high FVC and high mechanical properties, allowing designers to reduce wall thicknesses, using less resin and more simplified fiber reinforcement layups, which makes for a lighter blade. The superior mechanical properties also reduce the need for minor repair costs and maintenance by around 30%, generating additional savings.

Having lighter blades reduces bondline stress and root efforts. Fatigue failure of bondlines is mainly caused by the stress of edgewise loads which relate to the weight of the blade itself rather than the strength of the wind. The lighter the blade, the lower the edgewise loads and therefore, the lower the stress on the bondlines. Simulations show that a 5% blade weight reduction can improve the bondline lifetime by up to 50%, extending the overall blade lifetime by at least an additional 2 years, based upon conservative estimates.

Finally, advanced coatings for wind blades based on Covestro's PU raw materials help retain surface properties and significantly improve leading edge protection (LEP) in comparison to alternative solutions. Intact leading edges mean optimal (i.e., nearly as designed) aerodynamic profiles, less maintenance, less down time, and improved durabilty. Over the service lifetime, these coatings help to prevent losses in annual energy production (AEP) due to surface erosion.

Used in combination, Covestro PU solutions have a strong positive impact on blade manufacturing and operational performance, which significantly increase the value of wind projects and reduce the cost of electricity, as indicated in the case study of a representative offshore wind farm presented next.

FACTS AND FIGURES – Case study.
Simulating the use of Covestro PU solutions on 100 m offshore wind blades

Our partner bewind evaluated the benefits of Covestro PU solutions both for rotor blades manufacturing and wind turbine performance by means of their processing advantages and unique physical properties. Positive effects on rotor blade production, structural design and durability have been projected on a 12 MW offshore wind turbine with 100 m long rotor blades.

Assumptions: under the reference scenario, cost estimations use historical EMEA resin prices, production cost and labor time models. No additional Capex for a direct infusion machine was considered given that direct infusion is standard for new installations. The blades are considered the limiting factor for a turbine lifetime which, with conventional solutions, is limited to 25 years of operation, with LEP repair cycles of 5 years.

The reference case consists of a 100 m blade with the following design materials:	**The PU case study** used the same 100 m blade design, with the following substitutions:
conventional epoxy resin for infusion	**PU infusion resin**
pultruded spar caps based on vinyl ester + carbon fiber	**pultruded spar caps based on Covestro PU pultrusion resin + carbon fiber**
balsa core material	**PET foam core (price-identical to balsa).**
conventional LEP coatings	**LEP coatings based on Covestro PU raw materials**

The simulation identified 4 distinct benefits of Covestro PU solutions with significant potential for reducing LCoE, preventing the loss of annual energy production (AEP), and increasing the total energy generation of an offshore wind farm over the lifetime of the turbines:

Up to 8% reduction in blade manufacturing costs resulting from shorter production cycles and material savings.	Savings of up to 30% for minor repair costs and maintenance due to the high mechanical properties of PU composites and improved durability of LEP coating.
Additional energy production of up to 8% over the lifetime of the turbine thanks to potential blade weight reduction which alleviates bondline fatigue and extends the blade's lifetime by at least 2 years.	Working together, these solutions could reduce LCoE over the lifetime of a turbine by an estimated 2.4% and prevent the loss of efficiency, increasing average AEP by approximately 1%.

Larger, lighter and longer-lasting rotor blades

The benefits of PU composites create added value across the value chain. Covestro high-quality PU materials with improved processing properties (low viscosity and fast curing), enable blade manufacturers to benefit from a more efficient and cost-effective blade production process. This in turn generates benefits for wind farm operators by lowering LCoE and increasing energy productivity. Improved material properties in terms of fiber content, mechanical strength, and fatigue resistance offer opportunities for blade manufacturers to design new, improved blades, with better mechanical properties and lower weight parts, pushing the boundaries for blade designs, and increasing the production of clean and affordable energy. These features play a significant role in lowering the cost of energy and enabling the fast deployment of new wind capacity.

The solutions highlighted in this paper are available worldwide under the trade names: **Baydur®**, **Desmodur®**, **Desmophen NH®** and **Bayhydrol®**.

Click for more information:

#EfficientWindPower - Efficient wind power systems | Covestro | Covestro AG

Covestro Deutschland AG
Kaiser-Wilhelm-Allee 60
51373 Leverkusen
Germany

solutions.covestro.com
info@covestro.com

Edition: 2022 · Printed in Germany