In wind turbines, polyurethane offers three major advantages over materials such as epoxy resins and improves two key criteria of the turbines.

Polyurethane (PUR): Worldwide Demand for the Polymer Is Growing

Sustainability at Every Turn

All over the world, many polyurethane manufacturers are aligning production and assortment as well as upstream and downstream processes to the circular economy. Their goal is to become as climate-neutral as possible. The polymer can also contribute to greater sustainability in the products made from it. After all, it can be used to save weight, improve insulation and extend the life of products.

Following the decline in sales in 2020 due to the coronavirus pandemic, the global market for polyurethane (PUR) has recovered strongly and has now even clearly surpassed its pre-pandemic level: while sales in 2019 were still around 22 million t, in 2021 they rose to the record level of around 23 million t. Here, the strong growth was driven by all regions of the world. As in previous years, PUR consumption experienced above-average growth in the Asia-Pacific region (APAC), especially in China, closely followed by North America. Sales there increased significantly compared to previous years. In 2021, the APAC market was responsible for more than half of global sales and is anticipated to keep growing at a disproportionately high rate. The EMEA region (Europe, Middle East, Africa) is the second largest PUR market with a share of just under 30 %. North, Central and South America are in third place with a combined share of just under 20 %.

The market recovery covered all application segments for the polymer, but was less pronounced in the automotive sector than had been hoped. The reasons for this development also included supply chains disrupted by the coronavirus pandemic and, in particular, the chip shortage as a consequence of the global semiconductor crisis. Most car manufacturers therefore were forced to curb their production, which also had an impact on the demand for PUR. By contrast, the usage of PUR rigid foam systems for thermal insulation of buildings saw an extremely positive development against the backdrop of global efforts to protect the climate and preserve resources.

The global PUR market is expected to continue to grow by about 4 to 5 % annually in the medium term. However, the further developments of the war in Ukraine, the coronavirus pandemic and global inflationary trends present significant factors of uncertainty. Another factor that should not be under-

estimated and weighed up is the possibility of force majeure situations arising from severe weather, such as the winter storms in the south of the USA in 2021. They had a negative impact on the production of all important PUR raw materials, namely diphenylmethane diisocyanate (MDI), toluene diisocyanate (TDI) and polyols.

Global Capacity Expansion

While the focus for capacity expansion of the PUR precursors MDI and TDI continues to be on China, the growth of the PUR market is accompanied by the construction of new plants worldwide. This is especially the case for MDI given the expected strong development of market demand. Covestro, for instance, has resumed plans to build a world-scale plant for MDI and plans to announce the location decision in the second half of 2022. Commissioning is then planned for 2026. Furthermore, Covestro intends to complete the planned MDI expansion for 2025 in Tarragona, Spain, by 50,000 t/a to 220,000 t/a. The capacity of the TDI plant at the Dormagen site is to be expanded by debottlenecking in 2023.

BASF is also expanding its capacities. The chemical group completed the first phase of the gradual expansion of MDI production in Geismar, US, from 300,000 to 400,000 t/a at the end of 2021. The ultimate capacity of 600,000 t/a is projected to be available by about 2025. Chinese producer Wanhua increased its MDI capacity in Yantai by 600,000 to 1,100,000 t/a at the beginning of 2021. The expansion of the company's MDI plant in Ningbo in China from 1,200,000 t/a to 1,500,000 t/a is still underway. As part of a joint venture, Wanhua and local partner Fujian Petrochemical are also constructing a new MDI plant in Fuzhou in China with an annual capacity of 400,000 t. The project is scheduled for completion as early as the end of 2022. Wanhua is also increasing the capacity of a TDI plant acquired from Fujian Southeast Electrochemical at the same location by 150,000 t/a to 250,000 t/a.

In addition to the capacity expansion for the raw materials MDI and TDI, investments are also being made in new plants for thermoplastic polyurethanes (TPU) and PUR specialities. One example is the new production line for Desmodur 15 isocyanate prepolymers that Covestro recently commissioned in Barcelona, Spain. These prepolymers can be used to formulate ultra-high-performance elastomers for demanding tasks in the materials handling industry, for example. Moreover, Covestro is planning to expand its capacities for Platilon TPU films in Bomlitz, Lower Saxony, Germany, by the end of 2023 (**Fig. 1**). This investment addresses the growing global demand for multi-layer coextruded TPU films, which are used in automotive interiors, construction, wound care and outdoor clothing, among other applications.

Fig. 1. Covestro blown film line at the Bomlitz site: the plastics manufacturer is currently expanding the production of multi-layer coextruded TPU films there, as demand for them from various industries is increasing. © Covestro

ISCC Certifications Are in Demand

Most manufacturers of PUR raw materials and systems have now started to embrace the Circular Economy. Not only in the chemical industry is it regarded as a fundamental approach to combating climate change, using resources sustainably and »

Fig. 2. Climate-neutral MDI can be used, for example, to produce insulating elements made of PUR rigid foam. They provide efficient insulation for buildings. © Covestro

avoiding waste. The demand for circular products is on the rise in important PUR application areas such as energy-efficient housing and electromobility. For instance, Covestro is aligning its strategy clearly with circular business and aims to become climate-neutral by 2035. To achieve this, the company intends to invest EUR 1 billion in corresponding projects by 2030 in order to be able to operate in a completely circular manner in the future. The development of material cycles causes PUR manufacturers to use sustainable raw materials such as recyclates and bio-based materials for the production of rigid and flexible foams, casting systems, films or TPUs.

To prove the sustainability of renewable raw materials, the ISCC-Plus standard (International Sustainability and Carbon Certification) is used in addition to the REDcert2 certification, which is carried out by TÜV Nord, for example. This is an international system for the sustainability certification of biomass and biomass energy, among others. The standard certifies raw materials, products and even entire sites. Covestro has had production at its sites in Shanghai (China), Antwerp (Belgium), Krefeld-Uerdingen (Germany), Leverkusen (Germany), Dormagen (Germany) and Map Ta Phut (Thailand) certified according to ISCC Plus.

More Sustainable MDI and TDI

Both standards involve mass balancing during production. This method makes it possible to mix fossil and alternative raw materials in production but to separate them in accounting. As a result, sustainable raw materials can also be tracked through multi-stage production processes and be accounted for in the final products. The mass-balanced alternative raw materials are identical to their fossil counterparts, which they partially or fully replace. They are what is known as a drop-in solution. They can therefore be used on existing systems. This creates PUR systems with which processors can reduce the CO_2 footprint of their products and enter the circular economy.

MDI and TDI certified in accordance with ISCC-Plus as well as REDcert2 are now available on the market. BASF, for instance, has recently expanded its MDI portfolio to include the greenhouse gas-neutral Lupranat Zero. Covestro also sells renewable MDI grades that are climate neutral "from the cradle to the factory gate" (**Fig. 2**). The partial product life cycle from raw material extraction (cradle) to the factory gate (Covestro gate), also known as cradle-to-gate, is taken into account.

The methodology of this life cycle assessment, which has recently been critically reviewed by TÜV Rheinland, is based on ISO standards 14040 and 14044. It takes into account biogenic carbon sequestration based on preliminary data from the supply chain and no compensation measures have been applied. The MDI grades are based on plant waste and offer, for example, the opportunity to produce PUR insulation foams more sustainably and thus significantly improve the CO_2 bal-

Fig. 3. An important application for renewable, mass-balanced TDI are flexible foams for upholstered furniture. © Covestro

Fig. 4. The midsole for the Vaude Lavik Eco hiking shoe is based on the partially bio-based Desmopan EC 33000 TPU foam from Covestro.

© Vaude, Moritz Attenberger

ance of buildings. Covestro also offers renewable TDI grades (**Fig. 3**). These are also derived from plant waste, among other things. Sinomax, a manufacturer of comfort products, for one, is looking to use the significantly reduced CO_2 footprint of these products to reduce its CO_2 emissions. At the close of 2021, the company signed a supply contract with Covestro for such TDI grades. Circular TPU compounds are now also on offer. Since the beginning of the year, Covestro has been introducing ISCC-Plus certified TPU products to the European market. Previously, the company had already marketed several TPU products based on alternative, partly bio-based raw materials. One of them is used by the outdoor outfitter Vaude in the foam midsole of its Lavik Eco hiking boot product (**Fig. 4**). Another TPU product range is based on post-industrial recyclates (PIR) and is certified according to the Recycled Claim Standard (RCS), an international standard for tracking recycled raw materials within supply chains. These TPUs are found, among other things, in the protective cover of the Fairphone 4 (**Fig. 5**) by the Dutch manufacturer Fairphone.

Recycling of Flexible and Rigid Foams

A central role in the development of PUR material cycles is also played by recyclates and raw materials from end-of-life products and waste. The focus is particularly on flexible polyurethane foam because it is produced in large quantities when used mattresses and upholstered and seating furniture are disposed of. In this context, Covestro is partnering with Eco-mobilier, a French environmental protection organization and at the same time a non-profit system with extended producer responsibility for the collection and recycling of end-of-life furniture. Together, they intend to develop a business model for the efficient chemical recycling of mattresses made of polyurethane foams on an industrial scale. To this end, Covestro has developed a technology that, unlike most other processes, allows all the raw materials originally used to be recovered. A pilot plant is being operated at the company's Leverkusen site to further optimize the process. »

Fig. 5. The smartphone manufacturer Fairphone uses, among other things, TPU recyclate types such as Desmopan 3095AU RC100 in the protective cover of the Fairphone 3 and Fairphone 4. The fully recycled TPU is chemical and abrasion resistant and easy to process. © Fairphone

Other PUR manufacturers are also working on recycling concepts for flexible foam. For example, BASF is working with foam specialist Neveon to advance the recycling of mattresses and is developing a wet chemical process for this purpose. Repsol and Rampf Eco Solutions are also cooperating on polyol recycling from old mattresses. For this purpose, Repsol is building a plant in Spain based on Rampf technology. In September 2021, Dow Polyurethanes also commissioned a joint plant at the Orrion Chemicals Orgaform specialty chemicals company in Semoy, France, for the chemical recycling of discarded PUR mattresses. The plant will be used to recover polyols for the production of new flexible PUR foam products.

Fig. 6. In the case of insulation for refrigerators, for example, the combination of fast-demold PUR systems with new filling technologies such as multi-point injection improves the insulation performance. © Covestro

Rigid PUR Foams: Improved Insulation, Greater Production Efficiency

Another aim is to close the material cycle for rigid foams used in the thermal insulation of buildings and refrigerators. A total of 22 partners are cooperating under the leadership of Covestro in the EU innovation project Circular Foam. Chemolysis and smart pyrolysis are being examined as possible recycling paths. Here, the aim is to recover polyols and amines as raw materials of as high a quality as possible so that they can be reused in the production of rigid foam. The new EU energy label for refrigerators and freezers has once again intensified the requirements for the insulating performance of rigid PUR foams (**Fig. 6**).

To further reduce the thermal conductivity of the foams, highly reactive Fast-Demould PUR systems in combination with filling technologies such as multi-point injection are among the options. The PUR systems have already been successfully introduced to the market. They have the added advantage of enabling a considerable increase in manufacturing efficiency and higher utilization of production facilities. The latest developments in the field aim to reduce curing times by around half compared to conventional PUR technologies. Concurrently, the insulating performance of the foams is improved by 2 to 5 %. The density of the foams and key mechanical properties such as compressive strength remain unchanged.

PUR Increases the Competitiveness of Wind Turbines

One field of application for PUR with very good growth prospects is wind turbines (**Title figure**). This is because PUR can play a major role in making wind energy more competitive and cost-effective. That is the result of a study commissioned by Covestro and conducted by bewind GmbH, a global consulting firm specializing in wind energy technologies. The study was conducted to determine how the processing behavior and physical-mechanical properties of Covestro's polyurethane materials affect the manufacturing process of wind rotor blades and the performance of wind turbines. The simulation, using the example of a 12 MW offshore wind turbine with 100 m long rotor blades, revealed three significant advantages compared to conventional epoxy systems.

In rotor blade production with PUR infusion resins and pultruded materials, up to 8 % of costs can be saved through shorter production cycles and lower material requirements. The high mechanical property level of PUR also makes the rotor blades easier to design, which increases their service life from 25 to 27 years and results in a corresponding 8 % increase in energy yield. Combining the PUR systems with protective polymer coatings also makes the rotor blades last longer, reducing repair and maintenance costs by up to 30 %. Overall, this improves two key parameters of wind turbine efficiency: the cost of electricity over the lifetime of the turbine is reduced by around 2.4 %, while annual energy production increases by around 1 %.

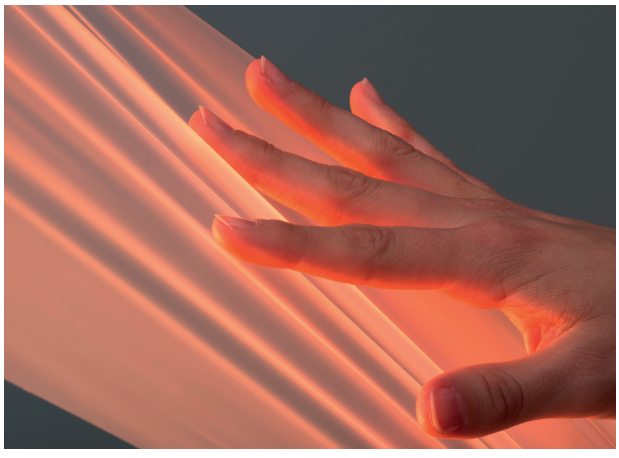

Fig. 7. Wound dressings based on matt multi-layer TPU films are comfortable to wear and stay on the skin longer because friction on textiles is minimized. Therefore, the bandages and patches need to be replaced less often. © Covestro

The performance of Covestro's polyurethane infusion systems for rotor blades has been certified by the international classification society DNV for global use, among other things in terms of resistance to aging. The DNV certificates allow the PUR rotor blades to be designed with lower safety reserves and therefore lighter. In order to better support international customers from the wind power industry in Europe as well, Covestro recently established a wind technology center in Leverkusen. It complements the existing Innovation Center in Shanghai.

PUR Foams for Lighter Vehicles

At present, many PUR developments for automobiles take the concept of lightweight construction very much into account. In view of the range of electric vehicles, this is an important focus in the automotive sector right now. In the case of PUR foams, some work is being done to save weight through lower foam densities. One such example is semi-rigid foams for instrument panels. Whereas the foam densities for these used to be 150 kg/m^3 and above, new PUR systems such as Bayfill 53IF71 from Covestro can reduce the density by 30 % at standard foam densities. The PUR system yields components with outstanding properties and can be processed in a stable manner. It also has the potential for lightweight construction in new design concepts for the instrument panel, such as thin-wall foaming. This means that wall thicknesses of only 3.5 mm and large thickness jumps in the foam layer can be implemented without any problems. Meanwhile, systems with reduced density are also offered for foamed armrests in the area of the door trim and center console.

The high weight of batteries for electric vehicles also creates new application opportunities for lightweight PUR composites such as pultruded materials. This is the case, for example, for components in the battery area such as frames, covers and supports. The stability of highly rigid and strong PUR constructions can outperform metallic solutions.

The electromobility trend is also leading to higher demand for PUR flexible molded foams for the "noise man- »

agement" of vehicles. On the one hand, the comparatively quiet electric vehicles must be shielded from outside noise, and on the other hand, they should be easily audible to pedestrians. PUR flexible molded foam is a particularly good solution for this because, among other things, it reduces airborne and structure-borne noise – and does so while remaining lightweight.

A promising automotive application for TPU films are lightweight, roll-up sun visors for large panoramic car roofs. The advantage of the light-stable and flexible hot-melt films is that they can be laminated very thinly and economically at low temperatures onto textile cover fabrics and are easy to color. This increases protection from the sun's rays. Covestro and Loomia Technologies have now co-developed a concept for these blinds that is aimed primarily at electric vehicles. It integrates lighting and heating into the blinds. Covestro also offers flame-retardant films from its Platilon range for such applications, which comply with the American FMVSS 302 standard (Federal Motor Vehicle Safety Standard).

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Data Basis and Sources

All market data is based on surveys and assessments by Covestro. Any additional information on investments and technical developments also comes from Covestro or from press releases issued by the companies mentioned.

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TPU Films in High Demand in Medical Technology

In the medical technology sector, TPU films are establishing themselves in wound care and in electronic patches worn directly on the skin. These so-called wearables measure and record vital parameters and support the patient with information. What makes these films so advantageous is that they are breathable, skin-friendly, abrasion-resistant and flexible and therefore very comfortable to wear. The move away from disposable products is also in demand for wearables. Covestro and its partner accensor have therefore developed wearable, intelligent patches with sensors (smart patches) based on TPU films. They consist of two elements: the disposable patch with the sensors for single use and the ReUse Patch, in which the remaining electronics are housed. The valuable electronic parts are thus reused.

A product innovation for wound dressings, plasters and other medical products that require high breathability is Covestro's Platilon XM matt, multilayer TPU films. The bubble films with polypropylene (PP) backing are offered transparent and in several skin tones. They are barely visible on the skin and therefore unnoticeable (**Fig. 7**). ■

More Flexible Design and Automated Manufacturing due to PPS

Metal Replacement for Solar Collectors

Solvay and Inaventa Solar, an innovator in solar thermal collector technology, joined forces in the development of the partner's new BI70 solar collector. The product leverages Solvay's Ryton polyphenylene sulfid (PPS) to replace metal, which provides significant benefits from greater design flexibility and automated manufacturing to simplified handling, better aesthetic facility integration and a lower carbon footprint. The combination of long-term heat resistance up to 160 °C, excellent hydrolytic resistance and processability makes Ryton PPS compound a good alternative solution for the solar collector's thermal absorber sheet, according to Solvay. Compared to metals, it facilitates a more flexible and efficient, automated manufacturing process for lightweight solar panels that save energy even before they are installed, by simplifying transport as well as handling on the construction site. The polymer also helps architects achieve a more seamless and aesthetic integration of the solar collectors into the roofs and façades of buildings, where they can replace other cladding components as active energy providers. Following initial installations at farms, schools, commercial and residential buildings in Norway and other Nordic countries, the cost-efficient and environmentally friendly solar collector will be available worldwide.

↘ **K 2022: Hall 6, booth C61**
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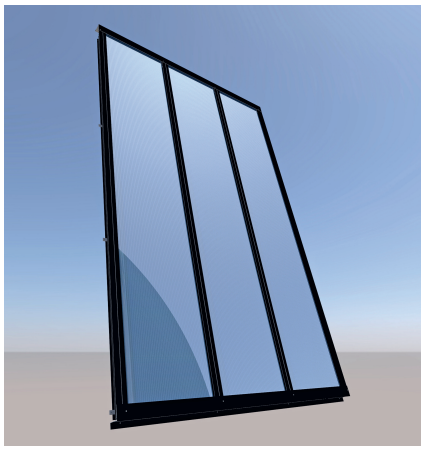

Replacing metal in solar collector designs with structural components extruded in Ryton PPS provides greater design flexibility and manufacturing cost-efficiency. © Inaventa Solar