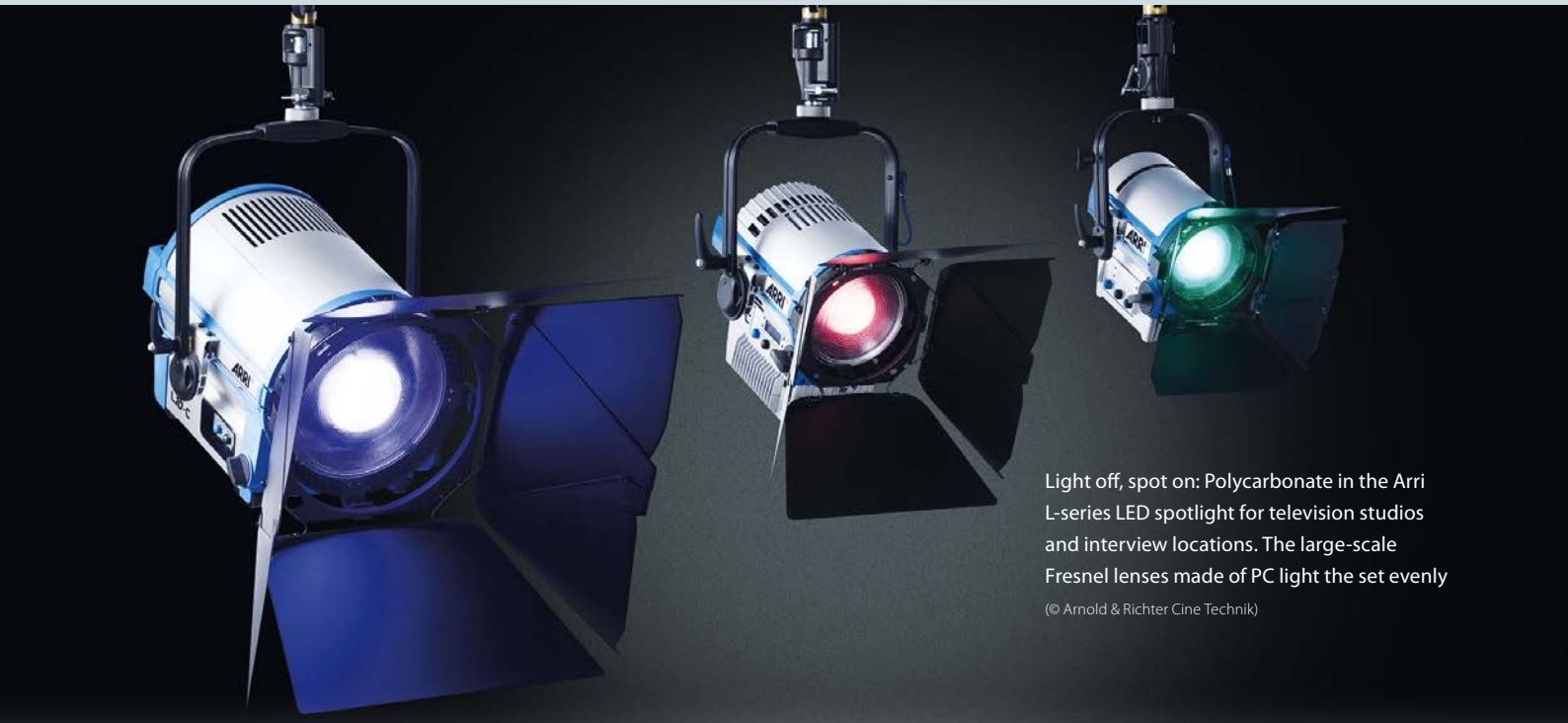

Light off, spot on: Polycarbonate in the Arri L-series LED spotlight for television studios and interview locations. The large-scale Fresnel lenses made of PC light the set evenly

(© Arnold & Richter Cine Technik)

Polycarbonate (PC)

The Crystal Clear Thermoplastic Material Is in High Demand, Especially in Asia, and Continues to Find New Fields of Application

Worldwide polycarbonate sales and demand will continue rising in the medium term. Growth drivers include new applications, for instance in LED engineering, automobile interiors and exteriors, and new technologies such as wearable electronics and robotics. Asian PC manufacturers in particular have recently consolidated or restructured their business. This restructuring is accompanied by an expansion of capacities, currently taking place exclusively in China.

Polycarbonate (PC) is offered in the market in powder and granulate form or – following an additional processing step – as semi-finished films or sheets. It is among the technical thermoplastics with good growth rates. These however are somewhat lower compared to prior years. Several factors are responsible for that. CDs, DVDs, and Blu-Ray discs for instance are increasingly being replaced by electronic storage media, cloud storage, or streaming services. Optical data storage media only hold a 10 % share of global PC consumption today, compared to around 25–30 % during the boom years of 2006 to 2008.

Applications in electrical engineering and electronics as well as the information and communication industry on the other hand are growth drivers, even though the wall thicknesses and therefore the consumption of materials were significantly reduced in recent years. This is due to the excellent mechanical properties of PC along with processing advancements. Since these segments are major fields of application for PC and its blends, this effect has a major impact as well. According to estimates by Covestro AG, Leverkusen, Germany, the electrical/electronics sector with a share of significantly over 30 % in the past year was the largest worldwide PC consumption segment, followed by consumer goods, household appliances, packaging, and the medical technology industry with 25 %. The automobile industry took 3rd place in the consumption ranking at 20 %, following by the construction sector at somewhat less than 15 %.

Healthy Sales in Germany and Europe

Global polycarbonate sales increased to around 3.9 million t in 2015. Demand is expected to grow by more than 4 % annually in the medium term. Economic factors in particular dampened PC growth in

2015. China's economy – the world's largest single local market, currently accounting for more than one-third of total consumption – became noticeably less dynamic. The crises in Russia and Brazil had an impact as well. Sales in Germany and Europe on the other hand developed favorably.

PC consumption in the Asia-Pacific region was highest with a share of nearly 65 %, followed by Europe, the Middle East and Africa (EMEA), jointly accounting for slightly more than 20 %. The NAFTA region including Latin America accounted for a share of over 15 %. The biggest sales increases are expected in the Asia-Pacific region over the coming years. Corresponding figures for Europe and the NAFTA region are much lower.

Fig. 1. Noise protection walls made of solid, transparent PC sheets withstand the effects of weather, stone chipping, and vandalism, permit a view of the surroundings, and are protected against bird strikes (© Covestro)

Restructuring and Consolidation

However, good prospects for PC in Asia should not mislead one to assume that these are "easy" markets. A lot of restructuring and consolidation has been seen over the last few years. Idemitsu Kosan Co., Ltd., Tokyo, Japan, for instance announced at the end of September 2015 that it intends to close its PC polymerization plant in Chiba, Japan, entirely by the end of the year, after previously decreasing capacities significantly from 47,000 t/a to 11,000 t/a. In parallel the company had already shifted the production of general purpose grades to the existing joint venture Formosa Idemitsu Petrochemical Corporation (FIPC) in Taiwan. According to the company, more competitive cost structures were the objective of this step. »

Fig. 2. PC filaments exhibit higher hardness and are more heat resistant compared to materials of this type common in the market. Corresponding products withstand temperatures far exceeding 100 °C without damage (© Polymaker)

Teijin Limited, Osaka, Japan, entirely eliminated its capacities of 225,000 t/a at the Jurong Island site in Singapore with the successive closure of four production lines by the end of 2015. High energy costs, the intended reduction of capacities in the commodity segment, and a future focus on PC types of higher quality (specialties) were cited as reasons. Polymerization capacities totaling around 400,000 t were taken out of the market worldwide through restructurings in the years since 2013.

An example of consolidation is the announcement by the conglomerate Samsung SDI Co., Ltd., Yongin, South Korea, in October of last year, intending to sell the PC business (240,000 t/a capacity in Yeosu, South Korea) to the South Korean Lotte Chemical Corporation, Seoul, in order to focus more on business areas such as electromobility. Lotte already has a PC capacity of 100,000 t/a at the Yeosu site. Mitsubishi Chemical Holdings Corporation (MCHC), Tokyo, Japan, is restructuring its business as well. It intends to combine the three subsidiaries Mitsubishi Chemical Corporation, Mitsubishi Plastics, Inc., and Mitsubishi Rayon Co., Ltd. into one company by April of 2017. Creating a more effective organization structure in order to better respond to market changes and facilitate expansion is the objective.

Outside of Asia, the Saudi Basic Industries Corporation (Sabic), Riyadh, Saudi Arabia, recently announced that it intends to dissolve the "Innovative Plastics" division and integrate it into the parent company. Assigning the various elements to a commodity and a specialty business is planned. According to the company, the specialty business is driven by technology acquisitions and partnerships while the standard plastics business is much more dependent on raw material innovations.

Capacity Expansion Exclusively in China

China with an annual growth rate of around 5 % is currently the fastest-growing local PC market. Thus capacities are being expanded only there. This is aided by the fact that the production of thermoplastics is identified as a preferred investment focus in the country's economic plans since local PC capacities are currently no longer sufficient. New Chinese manufacturers as well as external, established PC producers who frequently cooperate with local partners are appearing as investors. New players in their own country include Lihuayi Weiyuan Chemical Co. Ltd., Lijin, Luxi Chemical Group Co. Ltd., Liaocheng, Ningbo Zhetie Daphoon Chemical Co. Ltd., Ningbo, and Qingdao Hengyuan Chemicals Co. Ltd., Qingdao, among others.

Lihuayi is currently building its first PC plant at the Dongying site in the province of Shandong. Qingdao Hengyuan is also constructing its first facility in that province at this time, in Qingdao. Luxi announced the technical completion of a new facility with a capacity of 65,000 t/a in Liaocheng, also located in the province of Shandong, in the summer of 2015. Ningbo Zhetie Daphoon already put a new plant with a capacity of 100,000 t/a into operation in March of 2015 at the Ningbo site in the province of Zhejiang. Furthermore, the Wanhua Chemical Group Co., Ltd., Yantai, China, announced that the company's first PC plant is currently under construction. Other mostly Chinese firms have announced plans for the construction of PC facilities as well.

Covestro has also completed two additional production lines in Shanghai with a total capacity of 200,000 t/a. They will be put into operation in line with market developments in Asia. Then the company will be the largest PC manufacturer in China and the world. The Sinopec Corp., Beijing, China, and Sabic are planning the joint construction of a new PC

Fig. 3. The flame-retardant PC blends in the Bayblend FR4000 series from Covestro are for example suited as housing materials for electronic devices such as laptops (© Covestro)

facility in Tianjin, Hebei province, with a capacity of 260,000 t/a. The joint venture Sinopec Sabic Tianjin Petrochemical Company (SSTPC) has been operating an integrated refinery and petrochemical complex in Tianjin since 2010.

Overall the magnitude of investments in new PC facilities communicated in the market significantly overcompensates the loss of capacity due to worldwide restructuring measures described above.

In an opposing development, South Korean and Japanese PC manufacturers have been active in Europe with their own compounding facilities or also in cooperation with local toll compounding partners for several years already. Their activities mainly focus on PC applications in the IT sector, the electrical/electronics industry, and automobile construction. With Kingfa Sci.&Tech. Co., Ltd., Guangzhou, China, a major Chinese compounder is now also involved in Europe for the first time. The company opened its first production facility in Europe in Wiesbaden, Germany, during the summer of 2016.

Flexible Series – Customized Automobile Interiors

PC material development is currently driven by the trend towards customized vehicle interiors. From compact cars to the premium segment – individual, tailor-made design and styling versions that can be produced flexibly even in smaller numbers are in demand. Various PC manufacturers are pursuing an integrated material and process approach suitable for series production, allowing varied smaller series on the basis of high-volume standard platforms to be produced with special tooling concepts. Covestro has developed a corresponding approach called "Surface Technologies". With this broad-based technology approach, it is for example possible to produce lightweight components with excellent surface quality notwithstanding their rigid foam structure. This is done in an injection mold with dynamic temperature control using a foaming process.

PC-based films are increasingly playing a role in the decor, design, and display technology of automobile interiors. Hard-coat films that can be deformed in series production and harden in a two stage process, producing scratch-resistant 3D decorative surfaces with a deep gloss and/or graduated mattness levels and suitable for back-casting, are establishing themselves as a material for panels, for instance in the area of the center console. The spectrum of matt, deformable hard-coat films made of Makrofol HF (manufacturer: Covestro) ranges from matt, finely textured surfaces for diffuse light reflection to glare-free films to deep matt types.

Functional PC hard-coat films also play a central role in the development of large 3D touch screen displays and control panels. These will become increasingly popular for automobile interiors going forward. Such elements are built up from several layers of film and combine electronic, optical, haptic, and lighting technology functions in the smallest possible space. The standards for scratch resistance on touch surfaces are especially high. Covestro has developed multilayer films on the basis of PC and PMMA »

Fig. 4. The Marvelous three-way tap from Elcam Medical is made of polycarbonate. Its luer activated valve serves as a barrier against bacteria. A novel inner duct ensures self-cleaning and a minimal residual volume
(© Elcam Medical)

precisely for this application. Based on the good prospects for PC films, among other things for automobile interiors, the company intends to put a new co-extrusion plant into operation at the German Dormagen site in 2017 for high-end, multilayer PC flat films.

PC Panorama Roof with IR Absorption

PC panes are increasingly asserting themselves in automobiles in the interest of lightweight construction. In addition to fixed side windows, typical applications include large panorama roofs that are up to 50 % lighter than comparable glass-based component solutions. Such elements that have to meet extremely high surface quality standards are produced by injection compression molding. The world's largest injection molded, transparent coated PC automobile roof with IR light absorption was recently introduced to the market. It is being installed in the third generation of the Smart Fortwo and absorbs the IR spectrum of sunlight so the vehicle interior does not heat up as much.

Entire passenger vehicle hatch modules with an integrated pane are a far-reaching and technically future-oriented application. Incentives for realizing such complex and large lightweight construction components in PC are the integration of functions at lower cost, design freedom, and the ability to create a one-piece, seamless component of high complexity. PC panels with a scratch-resistant polysiloxane coating and a deep black gloss (piano black) are gaining importance in the fabrication of large chassis components. Typical components are B and C-pillars, sunroof frames, and antenna covers.

PC and its blends are also conquering new applications in the mobility segment beyond the automobile – on the interior of rail vehicles, in the production of batteries for pedelecs and e-bikes, or as transparent noise protection walls on streets (**Fig. 1**). The interior design of rail vehicles is a particularly demanding segment. Flame-protected, deformed PC blend sheets that are highly flame-retardant in case of fire and produce very little smoke gas, are resistant to vandalism, and offer great design freedom in regards to the color and surface are an example.

Thermoplastic Composites and 3D Printing with PC Filaments

The current trend towards lightweight construction using thermoplastic composites reinforced with continuous filaments also includes polycarbonate. Corresponding composites with a PC or PC blend matrix exhibit high strength and good stiffness with great design freedom. They are usually much more economical to process than comparable duromer systems. Covestro recently acquired Thermoplast Composite GmbH, Langenfeld near Nuremberg, Germany, a specialist for thermoplastic fiber composite materials, in order to offer its own composite products and technologies.

Possible fields of application are mainly found in lightweight automobile construction, IT, consumer goods, and transportation.

Reinforced PC materials are a possible alternative to aluminum in many applications. Covestro's cooperation with Nanodax Co., Ltd., Tokyo, Japan, is dedicated to lightweight construction with filled thermoplastic compounds. The company has developed a process to reinforce PC with mineral wool. Favorable opportunities for such materials are found for instance in IT, electronics, and the automobile industry.

Additive manufacturing methods such as 3D printing constitute a future market with good growth opportunities for PC. The methods are already being used successfully in rapid prototyping, the computer-controlled, cost-effective production of models, samples, and prototypes. Making the leap to industrial mass production is currently the object of research and development efforts. Various PC manufacturers are already working on materials suitable for mass production. Polymaker IIc., Shanghai, China, recently took a major step in this direction. It presented PC filaments for 3D desktop printers featuring low distortion, capable of being processed at comparably low printing temperatures (**Fig. 2**). Covestro supplies the PC base resins to Polymaker under a partnership.

PC for the Electrical/Electronics Industry and Medical Technology

The development of PC and its blends for electrical/electronics applications and various devices is taking several directions. Attempts are being made to further reduce the wall thickness of housing components and therefore their weight with the help of reinforced materials (carbon and continuous filaments). Flame protection packages are being further differentiated as well – for instance in the direction of halogen-free or easy to color formulations – without worsening the processing characteristics of the materials. Expanding the range of properties for flame-retardant materials is also among the objectives. One example is the Bayblend FR4000 material from Covestro. These PC blends include versions that are not only highly flame-retardant with outstanding mechanical properties, but also set themselves apart with, for example, excellent dimensional stability under heat, good toughness at low temperatures, chemical resistance, or UV resistance for outdoor applications (**Fig. 3**).

Medicine is another attractive field for PC applications. Here the growth potential results from the aging population of industrialized nations and medical care improvements in the emerging nations. Typical applications include injection systems (**Fig. 4**), inhalers, oxygenators, and dialyzers. PC blends are used for instance to produce components for medication delivery systems, surgical instruments, and housings of diagnosis equipment. One example of progress in the development of blend materials is the PC Makroblend M525 developed especially for portable medical devices in mobile patient care (manufacturer: Covestro). It is resistant to body lotions and skin care products. The casing of a capsule endoscope (**Fig. 5**) that is swallowed by the patient and transmits images of the stomach and intestinal wall is a new application for PC.

LED Lighting Technology Growth Market and Enhanced Safety

Lighting technology and especially energy-efficient LED lighting is another field with good growth prospects for PC and its blends. Products in the form of granulate, sheets, and films are processed »

Fig. 5. The PC material Makrolon used in the casing of a capsule endoscope is biocompatible and, thanks to its good moldability, makes a large camera opening angle possible
(© Shenyang Shangxian)

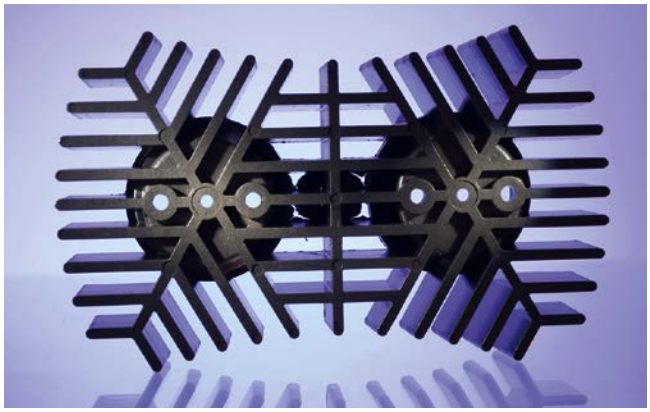

Fig. 6. The PC material Makrolon TC8030 (manufacturer: Covestro) exhibits high thermal conductivity of 20 W/m·K and is suitable for the production of heat sinks in complex shapes for LED lamps (© Covestro)

into lenses and optics, light conductors, diffusers, reflectors, housings, and even heat sinks. PC diffusers for instance easily withstand LED operating temperatures. They are lightweight, break-proof, and dimensionally stable, contributing to leak tightness for instance in lamps for outdoor installation. Thanks to the great styling freedom of PC, optics and lenses can be produced with precision to optimally guide and distribute light (**Title figure**). The appeal of making LED heat sinks from PC is that it can be easily cast to produce complex yet very lightweight rib structures thanks to its great design freedom, which cannot be realized with aluminum. PC is also more economical to process in large quantities than for instance die cast aluminum, and results in components of a lighter weight (**Fig. 6**).

PC sheets make large-scale light applications possible, such as those required in offices. Components with multiple optical functions can be fabricated from the semi-finished products in keeping with current trends. With Makrolon SX Shark for instance, Covestro supplies a transparent solid PC sheet with curved microprism optics on one side and a glossy surface on the other. The sheet combines very high light transmission with precise light guidance for glare-free lighting.

PC is firmly established in safety applications – especially where high transparency is demanded in addition to breaking resistance. Typical applications include visors, safety glasses, and entire helmets. Material development for this field of application is aimed at impact-resistant PC types among others. In the meantime, PC versions are even offered for bulletproof safety goggle lenses. The lenses pass tests in which they are impacted by steel bullets with a weight of 45 g at speeds of 45 to 120 m/s (**Fig. 7**).

PC films make it possible to stay a step ahead of counterfeiters with plastic ID cards. For example, films made of Makrofol ID Superlaser white (manufacturer: Covestro) allows the inside of passports to be personalized with the data and photo of the holder at an even higher contrast using laser engraving methods compared to laser-reactive standard overlay films.

Copolycarbonates with Special Monomers

The demand for copolycarbonates consisting of bisphenol A in combination with other special diol monomers is developing favorably. Some PC manufacturers are therefore expanding their capacities for preliminary products and polymers. Co-PC types on the basis of bisphenol A and bisphenol-trimethylcyclohexane (BP-TMC) for instance are used to produce components subject to high heat stress such as reflectors and transparent lenses for automobile headlights, lamp covers, or medical containers and instruments that can be sterilized using hot steam (132 °C, 143 °C). Polysiloxane co-polycarbonates with especially good low-temperature toughness, available in transparent, opaque, and flame-retardant versions, are offered as well.

PC types based on the renewable raw material isosorbide are finding initial applications. The transparent material Durabio from Mitsubishi Chemical for instance is being used in the touch displays of smart phones. In addition to its partially "renewable" origins, this thermoplastic material is sufficiently resistant to impacts, heat, and weather. Teijin is also offering an isosorbide-based PC material in the form of Planext, featuring good heat resistance and high impact resistance. ■

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Data Base and Sources

All market data are based on Covestro AG's own investigations and estimates. The additional information regarding investments and technical developments is internal or comes from the press information of the companies in question.

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Fig. 7. The lenses in safety goggles from MCR Safety are made of the impact-resistant PC material Makrolon 3207 of Covestro. They are lightweight, hard, and feature high optical quality and impact resistance in addition to good UV protection (© MCR Safety)