Fossil Raw Material Replacement – Demanding Vehicle Components from Sustainable Polyamide

The aspects of a sustainable circular economy and bottlenecks in supply chains are leading the chemical and automotive industries to increasingly develop and implement strategies for using secondary raw materials. Against this background, Mercedes-Benz, BASF, WITTE Automotive and Pyrum developed an external door handle made of a more sustainable, mass-balanced polyamide. Pyrolysis oil from scrap tires and biomethane from waste in the agricultural and food industry is assigned as raw material base to the certified product instead of fossil raw materials.

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With the Green Deal, the European Commission aims to achieve climate neutrality in the EU by 2050 by reducing Greenhouse Gas Emissions (GHG) to net zero. The transition into regulation for individual economic sectors occurs via industry-specific directives covering the production, use phase and end-of-use product recycling.

In 2021, the EU Commission's evaluation of recycling components and materials in vehicles at the end of their life per the EU End-of-Life Vehicle Directive (Directive 2000/53/EC) [1] will result in a revision in this directive. This review includes a stricter definition of material-related recyclate quotas and a regulation of measures for closed material cycles. A draft of the revised directive is expected in the course of the year 2023, with adoption by 2025, at the latest, and then translation into national law. As a result, resources are to be conserved and thus also the emission of greenhouse gases during the production of vehicles is to be reduced.

This revision poses significant challenges also for the plastics processing industry. Industry experts expect that the use of mechanically recycled plastics will not be sufficient to meet the requirements. For safety-relevant plastic components with high mechanical requirements or for applications in vehicle interiors with correspondingly low emission limits, high requirements regarding odor, absence of pollutants and fogging, high-quality plastic recyclates will (presumably) not be available in the required quantities. This situation is true if the recycled plastics are not produced based on production waste (post-industrial or pre-consumer) but are to come from so-called post-consumer waste.

Challenges also arise in the closed loop of plastics from end-of-life vehicles. These concerns are mainly dismantling and sorting but also preparing plastic components into reusable products. Only limited quantities of high-quality plastic recyclates are possible with today's standard shredding and processing technologies. Although research projects deal with developing these technologies further, cost-efficient recycling of engineering plastics will need to extend beyond mechanical processing techniques. Added to this is the fact that the plastic recoverable from end-of-life vehicles has been in use for an average of 17 to 18 years and has thus aged significantly more than is the case with packaging products with a short period of use [2].

Therefore, chemical recycling technologies are additionally being discussed, and numerous companies are already promoting their developments and commercialization, **FIGURE 1**. Therefore, experts from VCI, Dechema and PED advocate the practice of mechanical and chemical plastics recycling as complementary recovery routes. Depending on the plastic quality and composition, different technologies can be advantageous. In order to identify the best recycling routes, waste management and the chemical industry must work closely together [3].

CHEMCYCLING, PYROLYSIS OIL AND MASS BALANCE

In the chemical recycling of plastics by pyrolysis, the plastic molecules are split at elevated temperatures (300 to 700 °C) under absence of oxygen. The resulting pyrolysis gases are condensed into pyrolysis oil by a controlled cooling. In the so-called ChemCycling, the pyrolysis oil that meets specifications is then reintroduced into the chemical production network, for example, for plastics production and replaces fossil raw materials up to a certain percentage.

With various cooperation partners, including the companies Pyrum and Quantafuel among others, BASF has advanced the pyrolysis of used tires and plastic waste which are unsuitable for a mechanical recycling for technological, economic, or environmental reasons. The pyrolysis oils obtained in this way are commercially used today and converted into chemical products, including engineering plastics, at the Verbund site in Ludwigshafen (Germany).

The pyrolysis oil quantities currently already used at BASF pass through exactly the same production lines as the the fossil raw materials and are allocated to the chemical sales products purely virtually according to the mass balance approach, **FIGURE 2**. This so-called attribution principle is similar to the logic of green electricity contracts: Some customers purchase only green electricity according to an agreement, while all receive a randomly composed electricity mix. This distinction does not affect the generation and distribution of electricity via the electricity grids. Only an accounting allocation and settlement take place in the defined balance area. It must be demonstrably ensured that enough green electricity is introduced into the balance area to supply the existing green electricity customers accordingly.

Similarly, in ChemCycling, the mass balance approach is applied in order to produce mass-balanced materials using secondary raw materials in parallel to conventional materials without installing entirely new production facilities. Instead, only minor adjustments are necessary to use the pyrolysis oil on existing plants. The allocation of raw materials to sales products as well as the compliance with the mass balance of the ChemCycling products is audited and monitored by recognized certification schemes such as RedCert² or ISCC+.

Mass-balanced plastics have the same properties as conventionally manufactured products, can be further processed in the same way, and can be used in demanding applications. This approach applies equally to ChemCycling products based on pyrolysis oil from plastic pyrolysis and to the Biomass Balance (BMB) products described in the following, with biomethane attributed to the mass balance as the source of raw materials. The availability of pyrolysis oil is currently still limited. In addition to BASF, numerous companies in the chemical and petroleum industries are investing

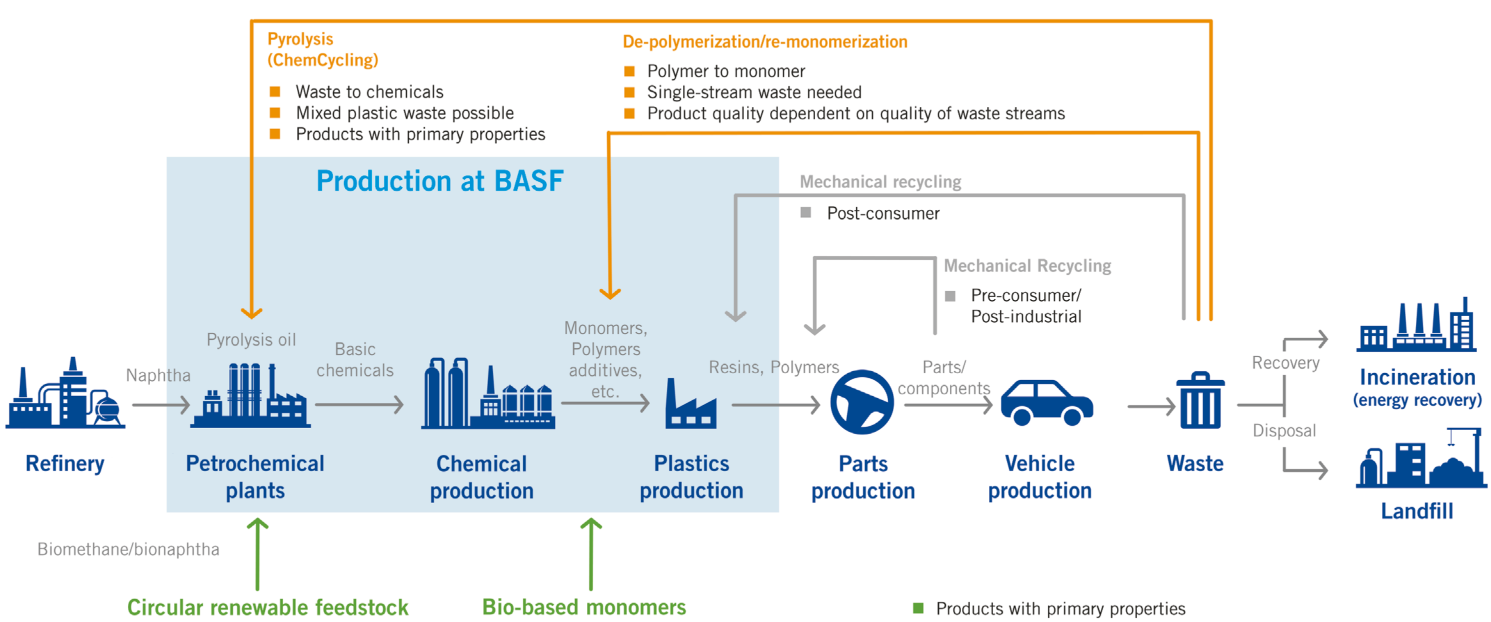

FIGURE 1 From linear to circular value chain at BASF: classification of recycling technologies (© BASF)

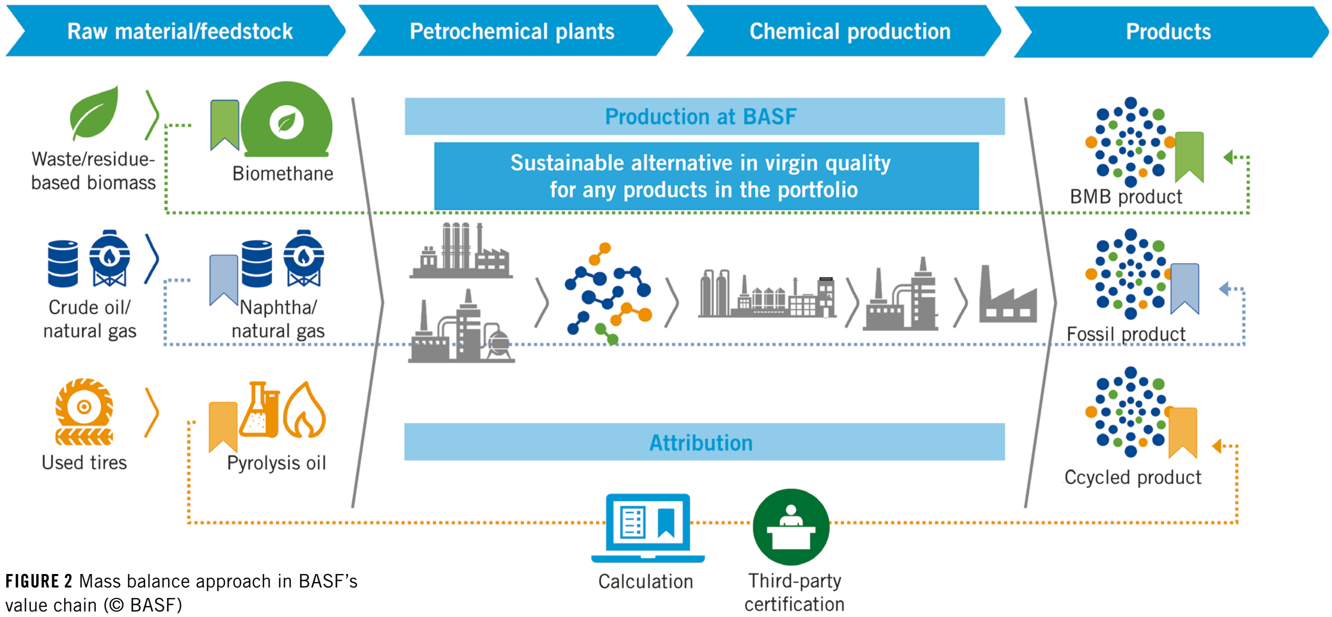

FIGURE 2 Mass balance approach in BASF's value chain (© BASF)

in developing and expanding capacities [4, 5] to meet rising demand.

RENEWABLE RAW MATERIALS AS A SUBSTITUTE FOR FOSSIL RAW MATERIALS

In addition to pyrolysis oils, renewable raw materials are increasingly used as secondary raw materials in chemical production. However, this requires their sustainable production, especially regarding land and water consumption and protecting areas with high biodiversity. In principle, chemical industries must minimize the resource competition with the food production. Therefore, renewable raw materials from organic waste from agricultural or food production are preferably used.

Waste-based biomethane has an enormous potential, which also attributes to chemical products according to the mass balance approach and can thus replace natural gas proportionately in their manufacturing. According to EU RED [6], biomethane is certified concerning its origin.

The currently produced quantities of biogas are only partially purified into biomethane and used as a raw material to produce chemical products such as plastics, **FIGURE 3**. However, a trend reversal from biogas power generation toward purification and feed-in into the existing gas infrastructure can be observed. Furthermore, there is a significant increase in capacities for biogas production to utilize the organic waste streams from the agricultural and food industry, which still need to be fully used.

EXAMPLE OF A DOOR HANDLE: POLYAMIDE COMPOUND AS A DROP-IN SOLUTION

Almost all vehicle manufacturers have anchored the goals of the Green Deal and the development of a circular economy in their corporate strategy. In its Ambition 2039 strategy, Mercedes-Benz consistently pursues the goal of balance sheet CO_2 neutrality along the entire value chain in its new vehicle fleet from 2039 on. A special attention is given to the careful use of resources. Therefore, the aim is to increasingly decouple resource consumption from growth in production output and reduce the use of primary resources per vehicle.

The objective of the cooperation project carried out by Mercedes-Benz, BASF, WITTE Automotive and Pyrum to replace fossil raw materials in the production of glass-fiber-reinforced polyamide for use in sophisticated vehicle components is derived from this strategy: resource conservation and reduction of CO_2 emissions while maintaining the high-quality requirements, especially to safety-relevant mechanical properties as well as the paintability of the target component.

The high-quality requirements for the target component, a bow door handle of the Mercedes-Benz EQE and S-Class series production models, largely exclude the use of recycled plastics from mechanical recycling. ChemCycling and the chemically recycled polyamide compound, on the contrary, achieve the usual properties of primary plastics and thus their suitability for the use in demanding applications. In this way, a drop-in solution became possible without retesting the material and component properties. Following an industry-specific recycling cycle philosophy, ChemCycling uses tires as feedstock for pyrolysis. The mass balance approach was advanced by simultaneously combining several sources of secondary raw materials, **FIGURE 4**. This results in a more sustainable, chemically and physically identical polyamide compound for the door handle.

In order to reduce the CO_2 footprint (Product Carbon Footprint, PCF) of the polyamide compound, biomethane was attributed in addition to the secondary raw material pyrolysis oil to produce the door handle. To achieve the targeted secondary raw material quota of more than 25 % by ChemCycling, the resulting pyrolysis oil share was 40 %. For the remaining 60 %, biomethane was the raw material source. The prod-

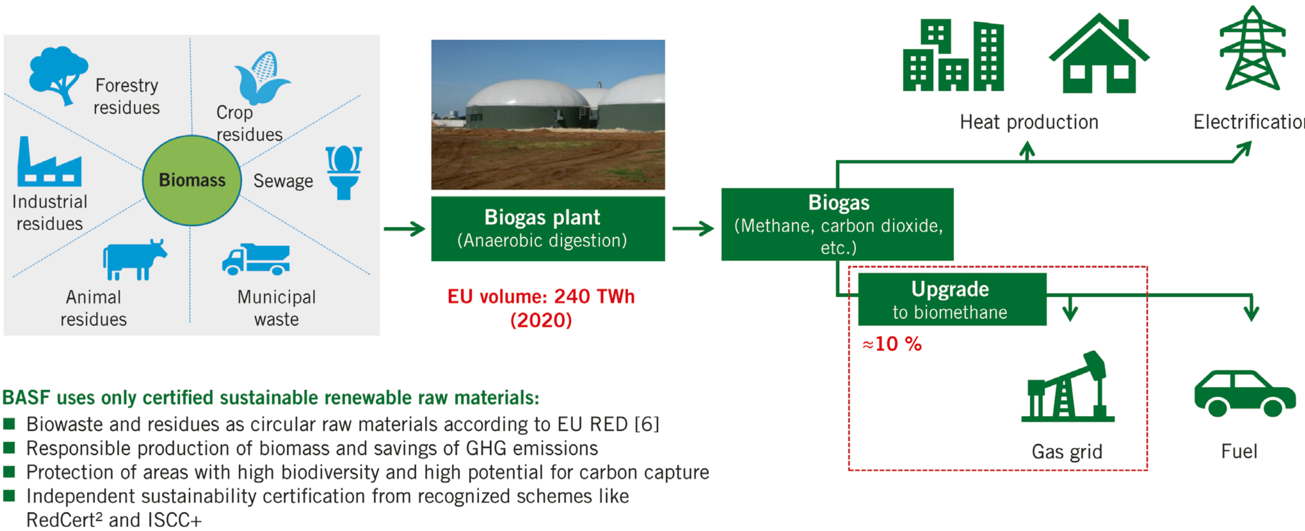

FIGURE 3 Origin and purifying of waste-based biomethane at BASF (© BASF)

uct defined in this way bears the product designation Ultramid B3WG6 GIT BC64 bk23328, where BC64 in the product name refers to the respective proportion of certified Ccycled and BMB material.

In the project, substituting fossil raw materials required for the end product by corresponding proportions of pyrolysis oil and biomethane was audited in cooperation with independent institutes and certified by TÜV Nord according to the RedCert² scheme. This was the very first audit of a product based on this advanced mass balance approach.

In addition to BASF as the manufacturer of the polyamide compound, the producer of the door handle, the automotive supplier WITTE Automotive, was also audited according to the RedCert² standard. The material transfer upon delivery as well as the material flows and the production processes within the company were relevant. After receiving the RedCert² certificates, the ongoing production of the door handles was able to be switched to the more sustainable polyamide compound at the end of 2022.

As a result of this project, BASF and Mercedes-Benz sent an amendment to the organization of the global International Material Data System (IMDS). After implementing the proposed adjustments in May 2023, it should enable recording of mass-balanced materials, including their sustainability attributes. Using the IMDS, it is possible to meet the obligations imposed on car manufacturers and their suppliers by national and international standards, laws, and regulations.

CALCULATION OF THE CO_2 FOOTPRINT

The greenhouse gases emitted during the entire manufacturing process of a product are summarized in the PCF and expressed in CO_2 equivalents per unit of a product manufactured. The

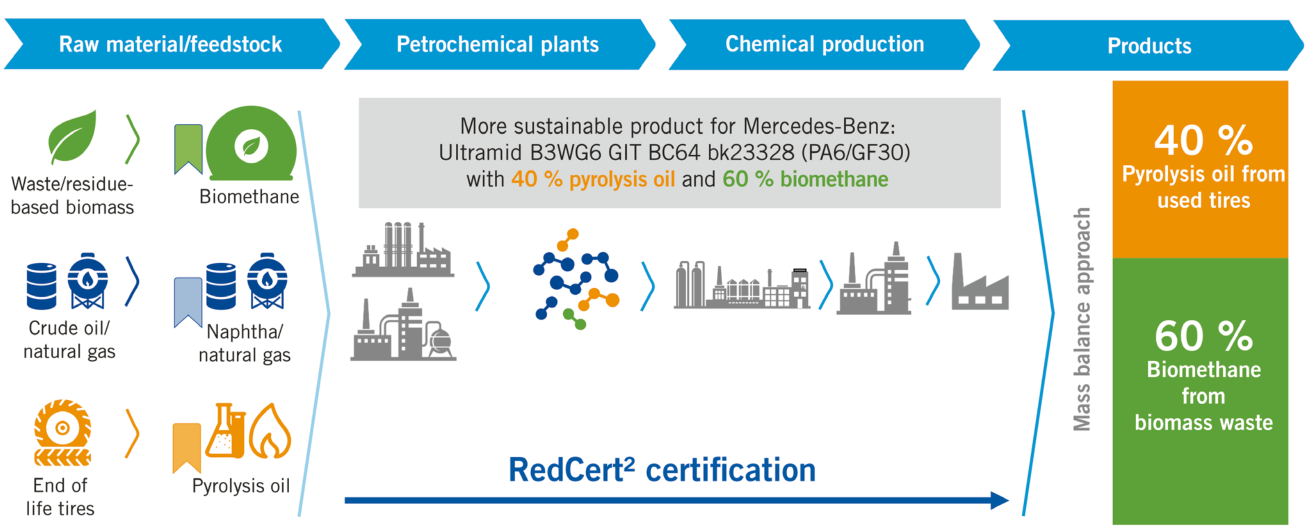

FIGURE 4 Advanced mass balance approach with combination of multiple sources of secondary raw materials (© BASF)

PCF value of a product is calculated in a cradle-to-gate balance. For this task, BASF has developed a software-based solution as an online tool. **FIGURE 5** shows the process steps 1 to 4 carried out there.

Within the scope of the project described here, several PCF calculations were carried out assuming different boundary conditions. Among other things, the PCF value for a product based on either 100 % pyrolysis oil or 100 % biomethane was determined, which then resulted on the other hand in the 21 % PCF reduction for Ultramid B3WG6 GIT BC64 bk23328 at the selected proportions (40/60).

Within the framework of the cooperation project, it became clear that the calculation methodology of the PCF is still causing discussions among experts in life cycle assessments. For this reason, BASF, together with other chemical companies, is involved in the Together for Sustainability (TfS) initiative, where it strives to improve the sustainability of its value chain. This initiative includes also the creation of a uniform standard for determining PCF values, which should enable for the first time a fair comparison of data from different manufacturers. The interactive online tool, **FIGURE 6**, for visualizing the concept is available on [7]. In addition, the Catena-X project is developing a cross-industry standard that aims to map the PCF as a digital twin throughout the automotive value chain.

A key success factor for this project results from trusting the cooperation of the participating companies of Mercedes-Benz, BASF, WITTE Automotive and Pyrum and the involvement of all relevant value chain stakeholders at every stage of the project. The result of the project and the cooperative design from idea to implementation in serial production was awarded the Materialica Award in the category Material with the Best of Award in October 2022.

OUTLOOK: FROM BOW DOOR HANDLES TO CRASH ABSORBERS AND OTHER COMPONENTS

The solution approach jointly developed for the bow door handle is currently being transferred to a crash absorber for the Mercedes-Benz S-Class. The component of the front end ensures an even force distribution to the other party involved in the event of a frontal collision. Here, too, a mass-balanced plastic compound using pyrolysis oil and biomethane meets the high-quality requirements, especially regarding crash safety. As with the bow door handle, the crash absorber switches to the more sustainable polyamide compound as a drop-in solution without additional material respectively component qualification.

Further flexibilization of the mixing ratio of attributed pyrolysis oil and biomethane will be even more effortless in

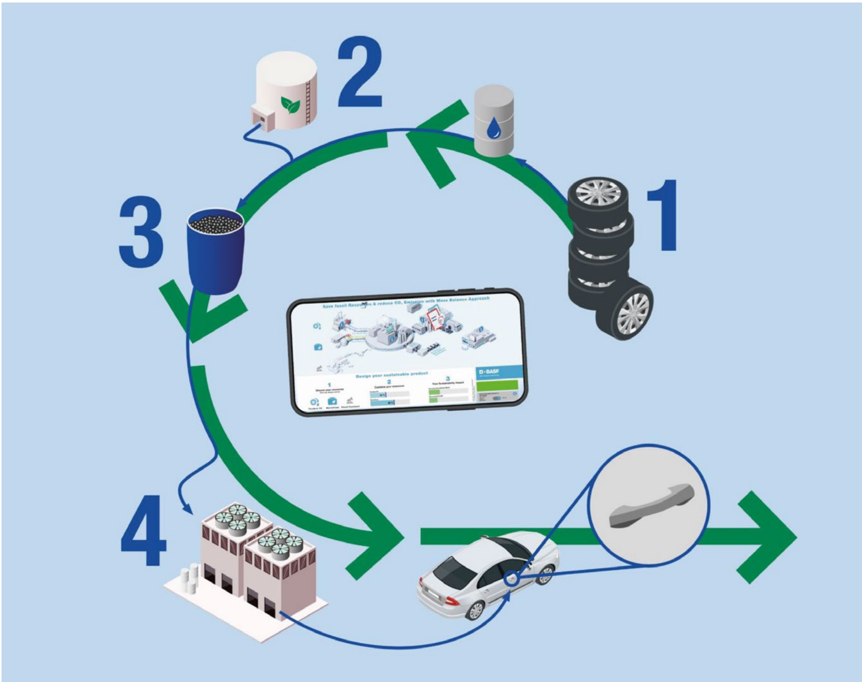

FIGURE 5 Process steps 1 to 4 depicted in the project and online tool: CO_2 consideration from used tire to new door handle (© BASF | Stern GmbH)

the future. BASF is currently preparing the internal supply chain and ERP systems for a digitized attribution, which will make it possible to adapt the sustainability attributes of a plastic product in the ongoing series production of the plastic component. This adaption will open further options for applications of the combined mass balance approach for other components based on pyrolysis oil and biomethane.

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FIGURE 6 Interactive online tool for the visualization of the combined mass balance approach [7] (© BASF)

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