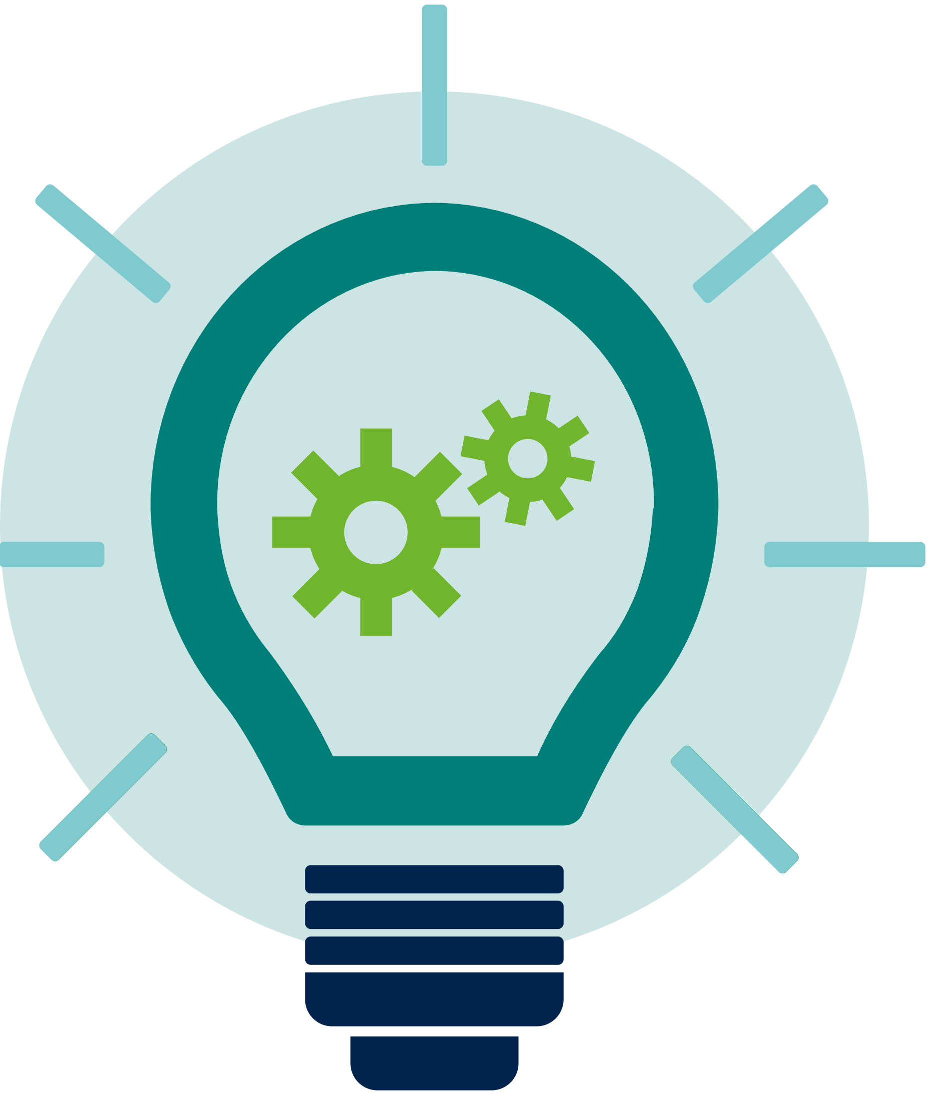
TransBiB
Boost. Industrial. Bioeconomy.



Fiber-reinforced plastics

Composite materials – conventional & based on natural fibers

Discover – Develop – Connect

Gefördert durch:

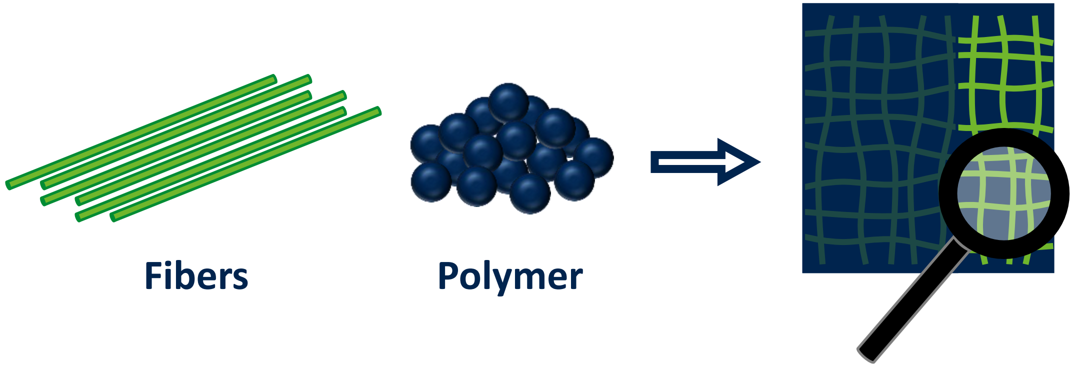
Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

Content

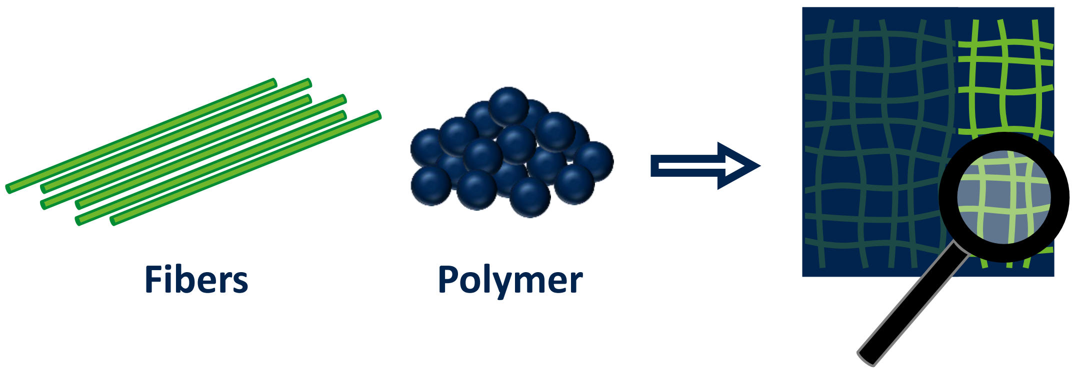
Composite materials

Fundamentals



- Plastics and polymers in general can be reinforced in terms of their **mechanical strength and stiffness.**
- Reinforcement is achieved by **embedding fibers in the polymer matrix** to create a composite material (FRC = *fibre-reinforced composite*).
- Typical fibers used in industrial applications are **carbon or glass fibers and polymer fibers** (e.g., aramid).

Fundamentals



- The fibers reinforce the material, while the polymer matrix holds them together, protects and **distributes mechanical stress.**
- Fiber-reinforced polymer composites are characterized by **high load-baring capacity and mechanical strength** at low weight (good strength-to-weight ratio) and good durability.
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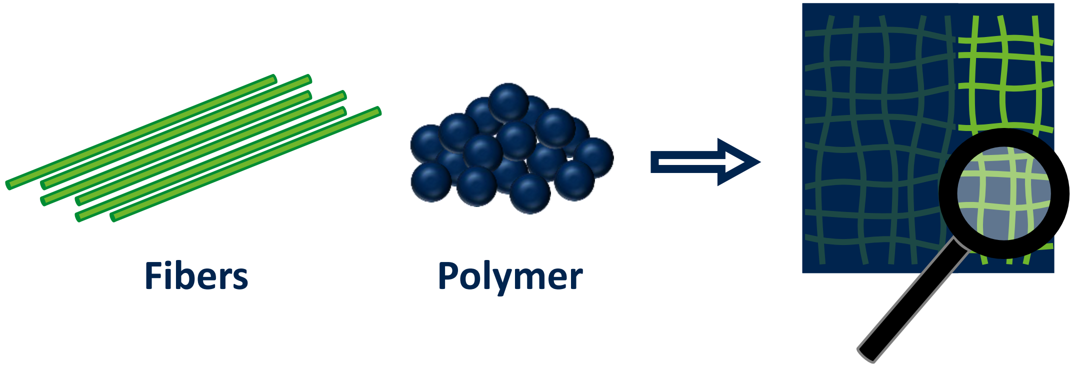

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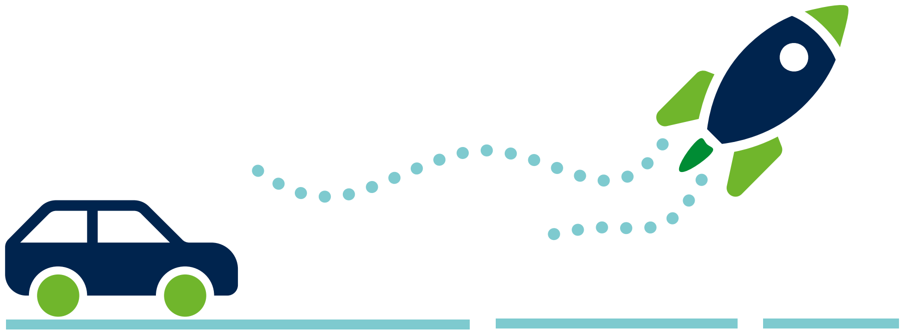
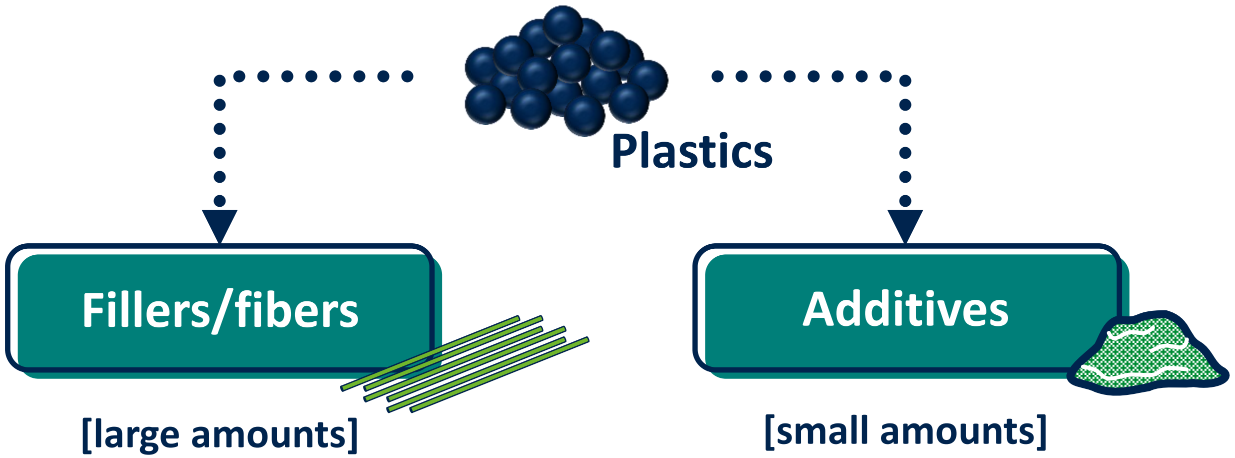
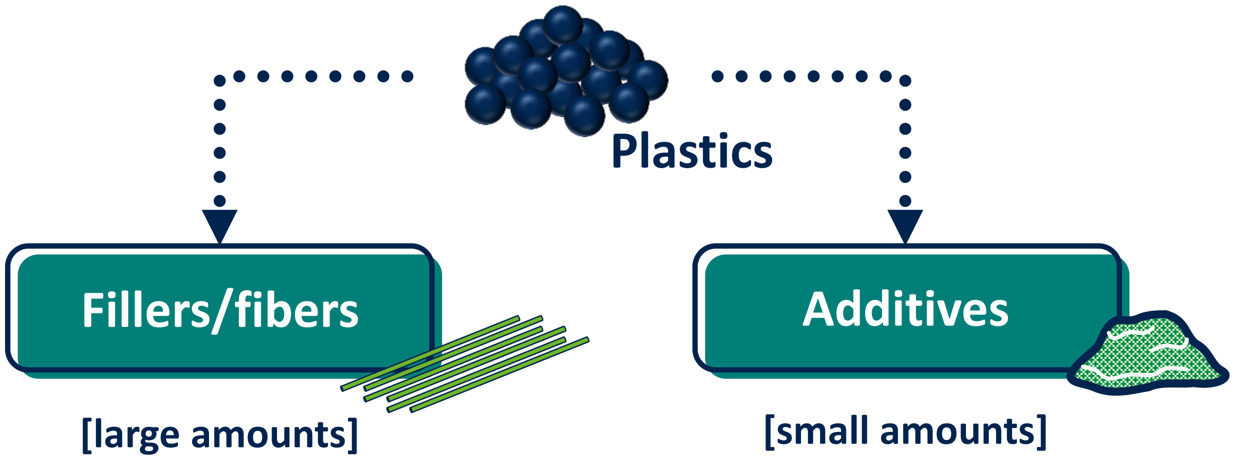


- **Typical applications** are in automotive, aerospace, construction, and the sports industry, where **high material strength and low weight** are required simultaneously.

Filler vs. additive



Filler vs. additive



- Lime/chalk
- Soot
- Fibers

Waste:

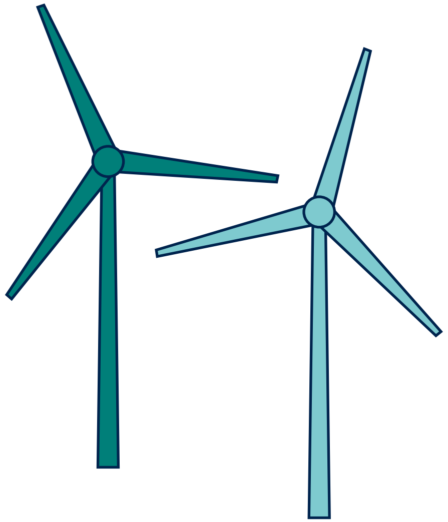
- Wood flour
- Duromers

- Protective agents
- Stabilizers
- Flame retardant
- Plasticizers
- Color pigments
- Adhesion promoter...

To achieve an optimal **composite material,** both the **compatibility of matrix and fiber** must be ensured and the **production process** must be optimized in order to control, e.g., the alignment and distribution of the fibers.

Sustainability

- Carbon and glass fiber production generates **large amounts of CO_2.**
- The production of these fibers consumes **large amounts of energy.**



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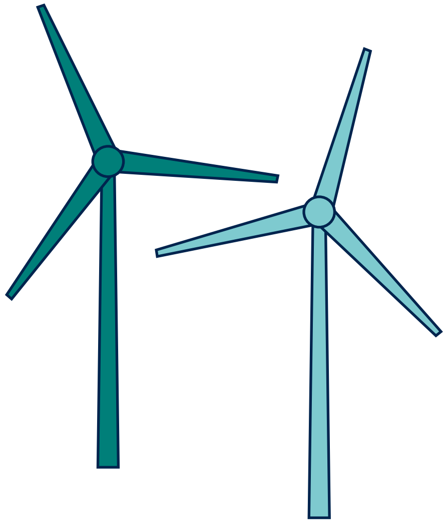

- The **recycling** of fiber-reinforced composite materials poses a **major challenge.**
- The **strong bond** between fibers and matrix **makes subsequent separation challenging** -> there is a high risk of **destroying the fiber** and **contaminating the polymer material.**
- **Recycling methods** are currently still being developed and are **not universally applicable.**
- Many processes (e.g., mechanical and thermal recycling) are **expensive and energy-intensive.**

Types of fibers

Plant fibers

- Trunk (wood)
- Bark
- Stems / stalks
- Leaves
- Fruits / seeds

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Animal fibers

- Bristles / coarse hair
- Wool
- Fine hair
- Silk

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Mineral fibers
- Asbestos
- Basalt
- Wollastonite
- Whisker (hair crystals)

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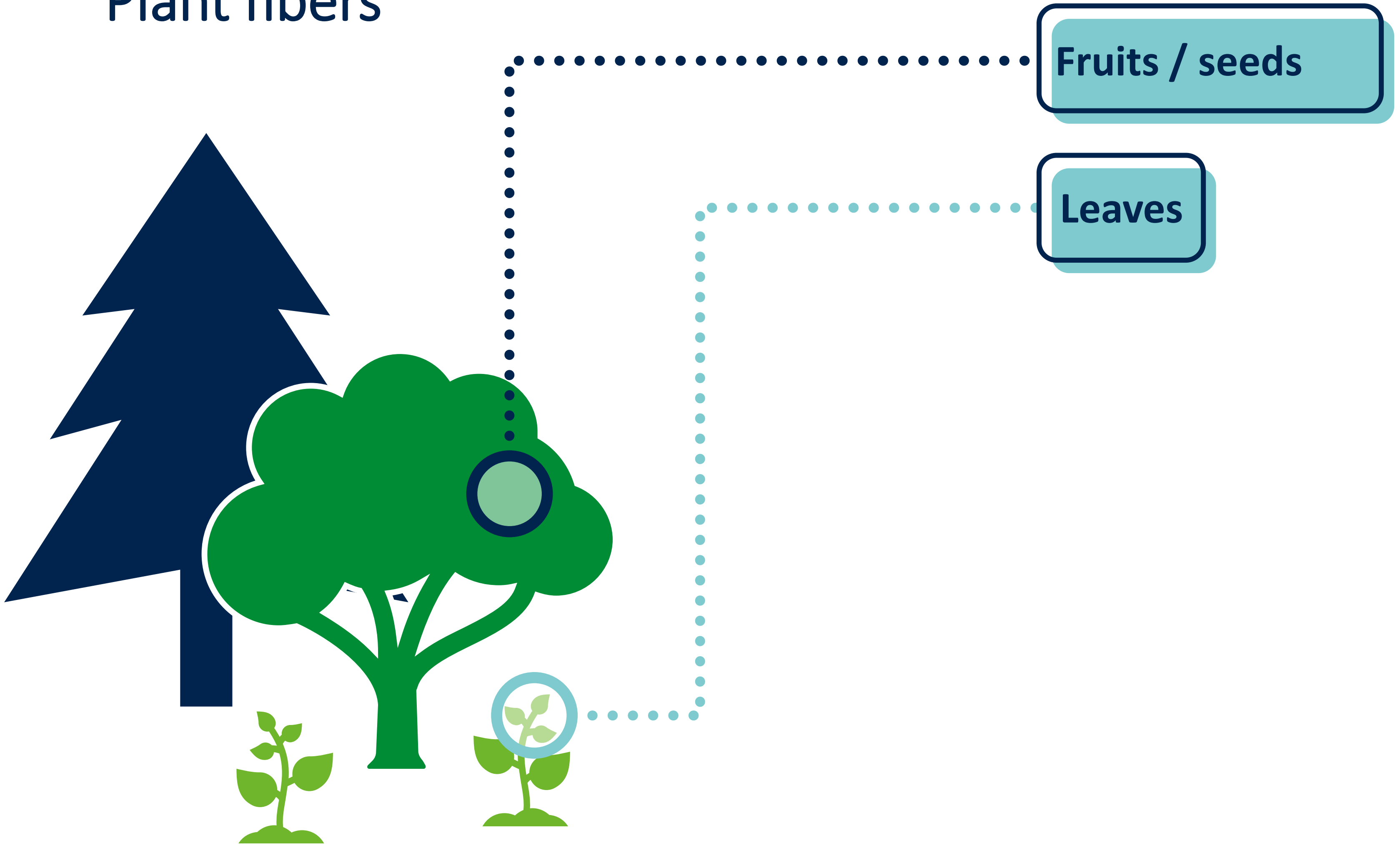
Synthetic fibers
- Polymers (e.g., aramid)
- Glass (GF)
- Carbon (CF)

Plant fibers

Fruits / seeds

Coconut fiber
Cotton

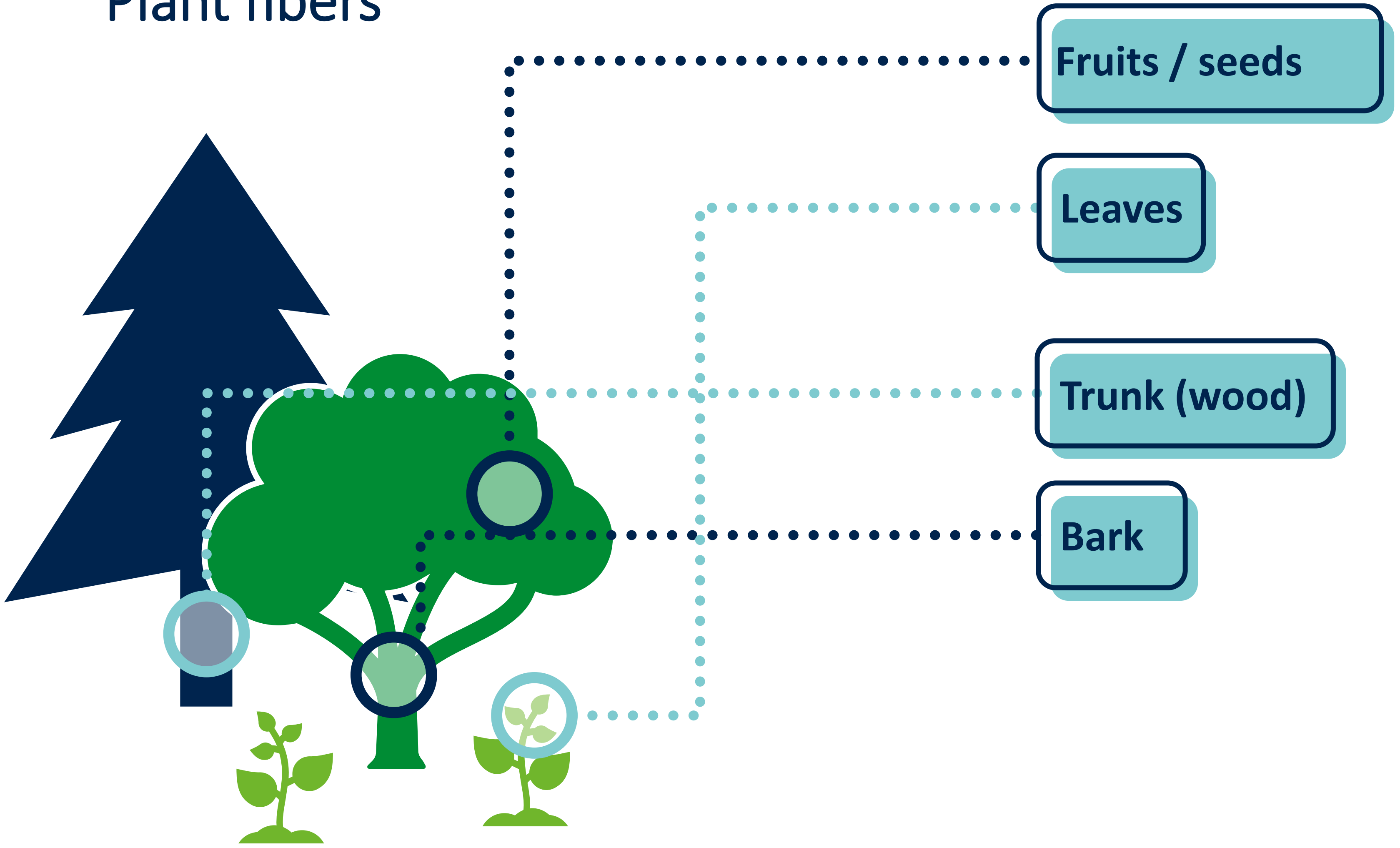
Plant fibers



Coconut fiber
Cotton

Abaca
Sisal

Plant fibers



Coconut fiber
Cotton

Abaca
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Rattan
Hardwood & softwood

Plant fibers

Fruits / seeds
- Coconut fiber
- Cotton

Leaves
- Abaca
- Sisal

Trunk (wood)
- Rattan
- Hardwood & softwood

Bark

Stems / stalks
- Stinging nettle
- Miscanthus
- Hemp
- Jute
- Linen / ramie
- Kenaf

Fiber lengths

Short fibers
0,1 – 1 mm length

Suitable for:
Injection molding
Extrusion

Long fibers
1 – 50 mm length

Suitable for:
Injection molding
Extrusion

Continuous fibers
>50 mm length

Suitable for:
Rovings (fiber bundle)
Mats

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Suitable for:
Injection molding
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Miscanthus: 0,5 – 3 mm

Long fibers
1 – 50 mm length

Suitable for:
Injection molding
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Wood: 1 – 5 mm (softwood > hardwood)

Cotton: 10 – 35 mm

Hemp: 5 – 55 mm

Continuous fibers
>50 mm length

Suitable for:
Rovings (fiber bundle)
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Ramie: 60 – 250 mm

Coconut: 100 – 300 mm

Linen: 250 – 1500 mm

Sisal: 0,6 – 1,2 m

Jute, Abaca, Kenaf: 1,5 – 3,5 m

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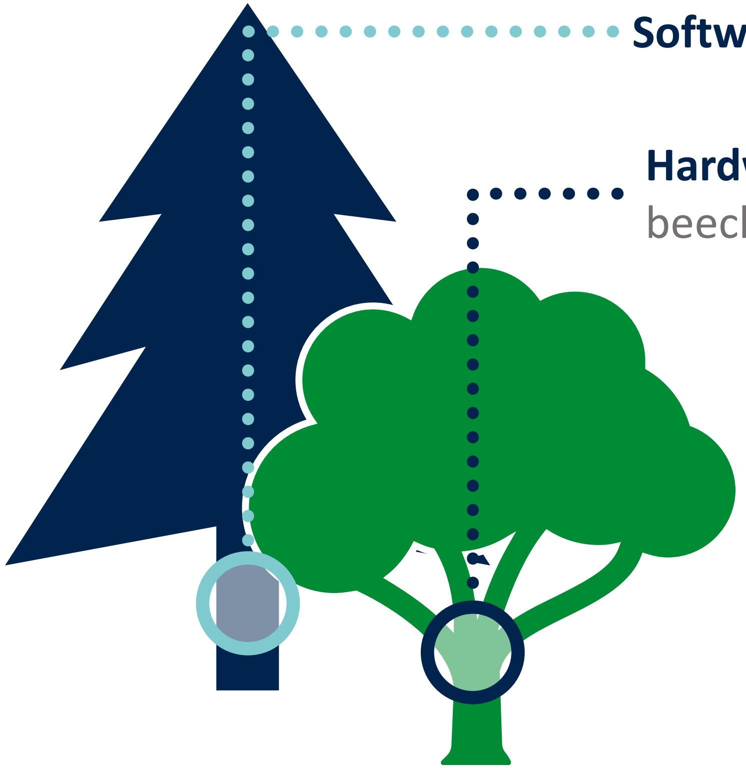
- In principle, **any fiber in nature can be incorporated into plastics as filler.**
- **Important factors are:**
  - Availability/quantity
  - Quality
  - Stability (thermal, mechanical, chemical)
  - Processing temperature
  - Mechanics

Wood fibers and flour

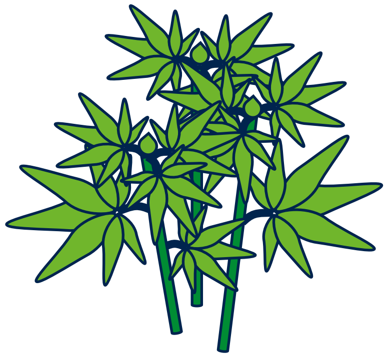


Softwood (e.g., fir, pine, birch)

Hardwood (e.g., spruce, beech)

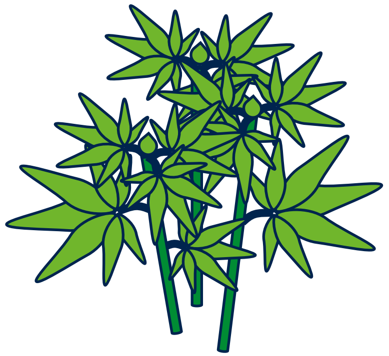
- **Wood fibers** are different from **wood flour** (= destroyed fibers)
- Composite materials from polymer and wood are called ***Wood-Polymer-Compound*** **(WPC).**
- Wood flour is classified as **filler** and can be incorporated with fill levels of **20 - 70 % Füllgrad** into composite materials.
- Decomposition temperature: approx. 200 °C
- PE and PP are often used as matrix material.

Hemp as fiber plant



- Requires **little to no treatment with pesticides or herbicides.**
- Suitable for **soil regeneration**
- **Low water demand**
- High **CO_2-binding**
- Harvested 1-2 times/year (problem: german regulations require growth until (unnecessary) full bloom)

Hemp as fiber plant



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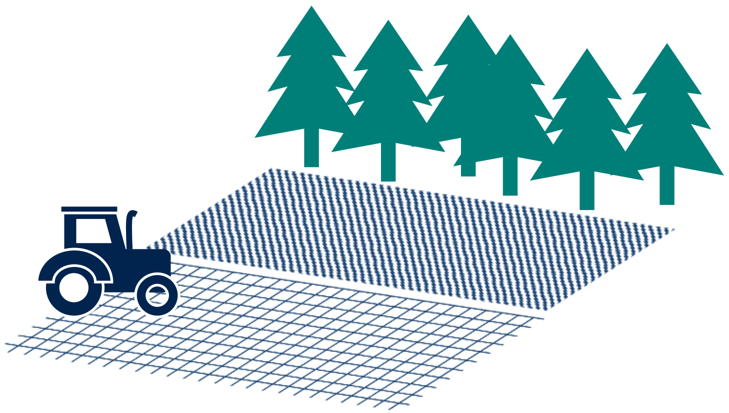
- Most widely used in the Middle Ages for textiles (clothing, canvas, ropes, etc.).
- **Ban on cultivation** led to drastic decline in hemp cultivation.
- Lifting of the ban on cultivation has led to **renewed growth in cultivated areas.**
- Hemp is used as **insulation material, specialy pulp, composite material or filler.**



Biobased synthetic fibers

Synthetic fibers	Biobased alternative
Polymer (e.g., aramid)	Bio-PE Bio-PA Bio-PET PLA Cellulose derivatives
Glass (GF)	✗
Carbon (CF)	Lignin Cellulose

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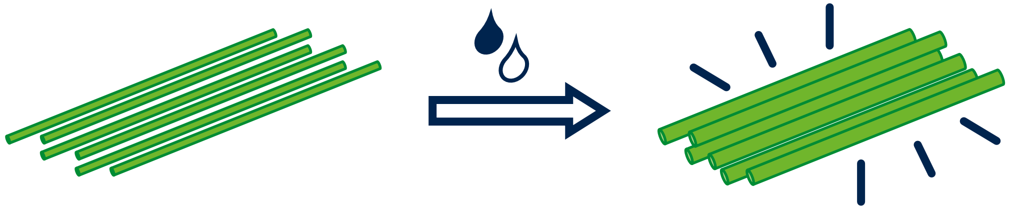
- **Polymer fibers** for composite materials can be partially produced from **renewable raw materials.**
- With the same chemical composition, they are referred to as **drop-in solution** that can be processed identically.
- **Carbon fibers** can be produced from **lignin or cellulose** instead of conventional polyacrylnitrile.
- **Please note:** the use of bio-based fibers does not result in **improved recyclability!**

Processing

- Natural fibers often posses **hygroscopic properties**, i.e., they easily absorb significant amounts of water/vapor.
- Moisture can cause the **fibers to rot** before processing.
- **Dosage** (fiber/matrix ratio) is impaired and **distribution problems** may occur (e.g., bridging between fibers).
- Moisture leads to uncontrolled material distortion during processing – **formation of streaks and bubbles in the material** can be expected.



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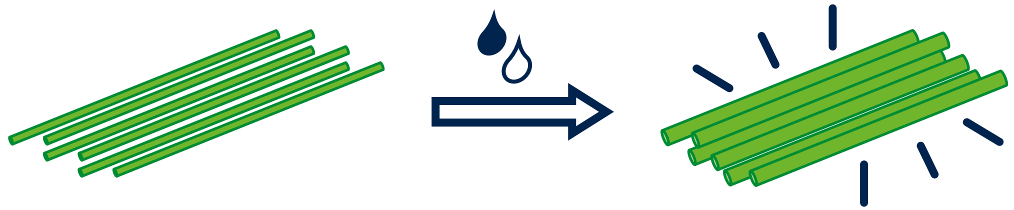
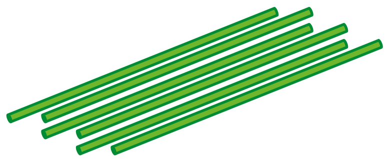
Polymer	Processing temperatur [°C]
PE	150 – 200
PLA	150 – 180
PA	200
PP	200 – 280



- Hot air drying is necessary.
- **Processing temperatures** of technical polymers are usally at approx. **150 – 290 °C.**
- **Decomposition temperature** of natural fibers is usually around **200 °C.**

Compatibility with plastics

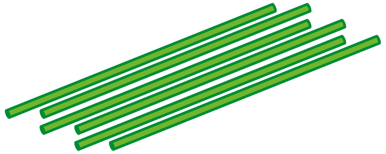
Pot. good compatibility



Natural fibers
usually polar (hydrophilic)

Pot. low compatibility

Compatibility with plastics



Natural fibers
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Pot. good compatibility → **Polar plastics e.g., PA, PC**

Pot. low compatibility → **Nonpolar plastics e.g., PE, PP**

- Agglomeration
- Segregation
- Poor wetting

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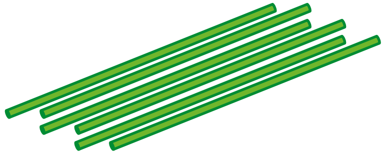


Natural fibers usually polar (hydrophilic)

Pot. low compatibility → **Nonpolar plastics e.g., PE, PP**

- Agglomeration
- Segregation
- Poor wetting

⇒

Dispersing agent

- Posses **interfacial activity**
- Decreases **interfacial tension** between materials
- Improves **mechanical properties**
- Exampels: waxses, **bifunctional peptides**

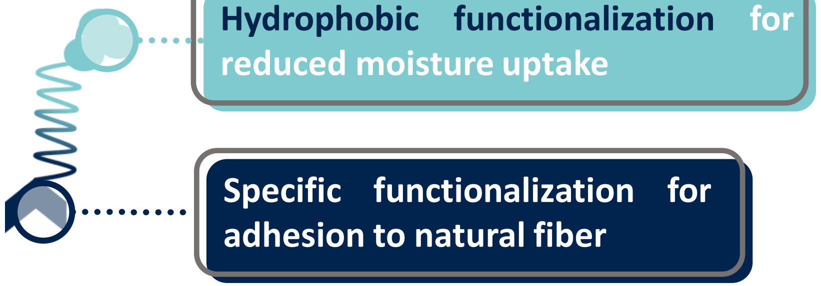
Comparison of properties

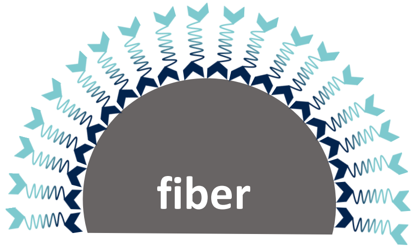
	 Natural fibers	 Glass fibers	 Carbon fibers
Density [g/cm³]	1,5	2,6	1,7 – 1,9
Costs [€/kg]	0,5 – 3,5	2	18 – 500
Accoustic	dampening	-	-
Tensile strength [GPa]	0,3 – 0,9	1,8 – 5,0	2,4 – 7,0
Spec. tensile strength [Nm/g]	200 - 600	700 – 1900	1400 – 3700
E-modulus [GPa]	10 – 25	70 – 90	230 – 700
Splintering likeliness	low	high	high

Key technology: biobased coatings

Bifunctional peptides as biobased impregnation

- **Material-specific bonding** to natural fibers
- **Hydrophobic functional domain** acts as **barrier** against moisture uptake and fiber swelling
- Thickness of coating is **less than 100 nm**
- Functionalization is realized by **standard coating methods** (e.g., spray coating)
- Purely **biobased coating** with biodegradability

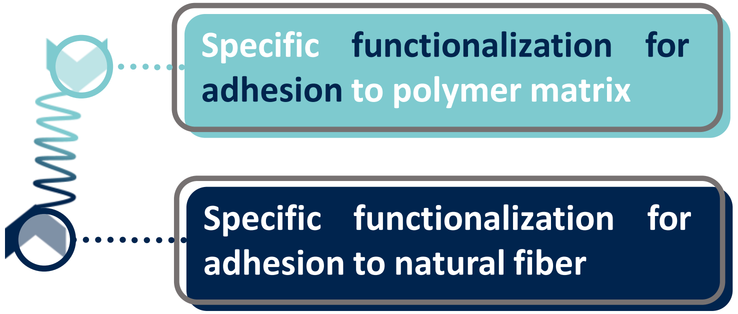


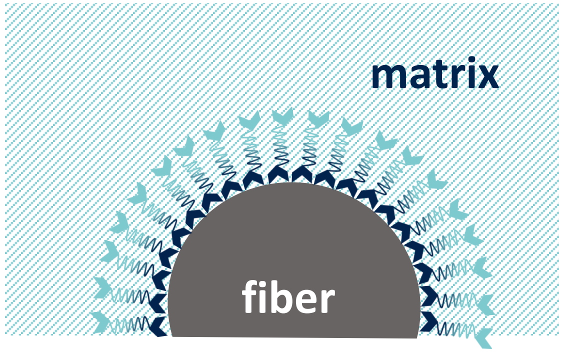


Key technology: biobased coatings

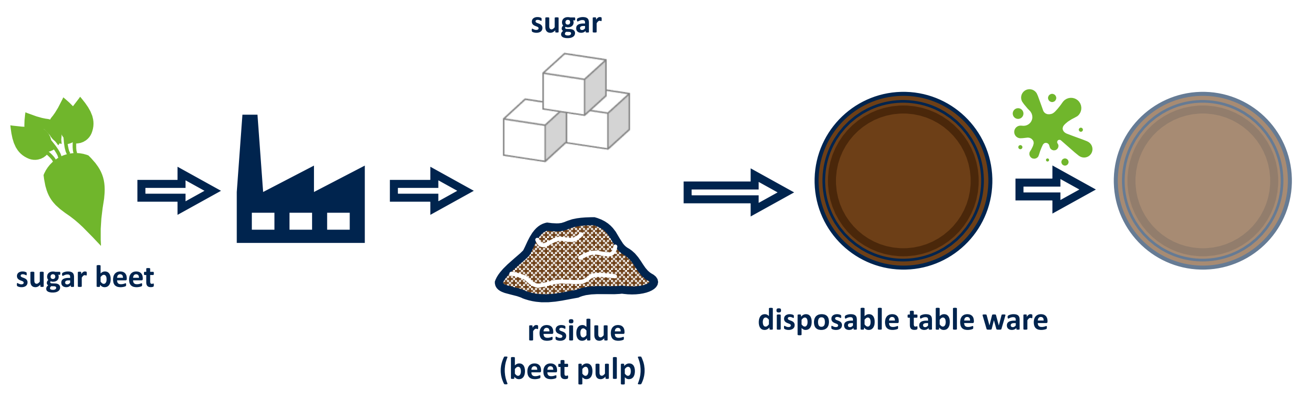
Bifunctional peptides as biobased adhesion promoters

- **Material-specific bonding** to natural fibers and polymer matrix -> **overcoming interfacial tension**
- Thickness of coating is **less than 100 nm**
- High **occupancy density**
- Functionalization is realized by **standard coating methods** (e.g., spray coating)





Use Case: Biogenic residues as fibers and fillers



Sugar beet pulp as a raw material for compostable disposable tableware

- Controlled material supply
- Recipe **without synthetic/hazardous additives** (starch, pectin, glycerine, water)
- Funktionalization by **biological coating**

Research by:
Project EBRA

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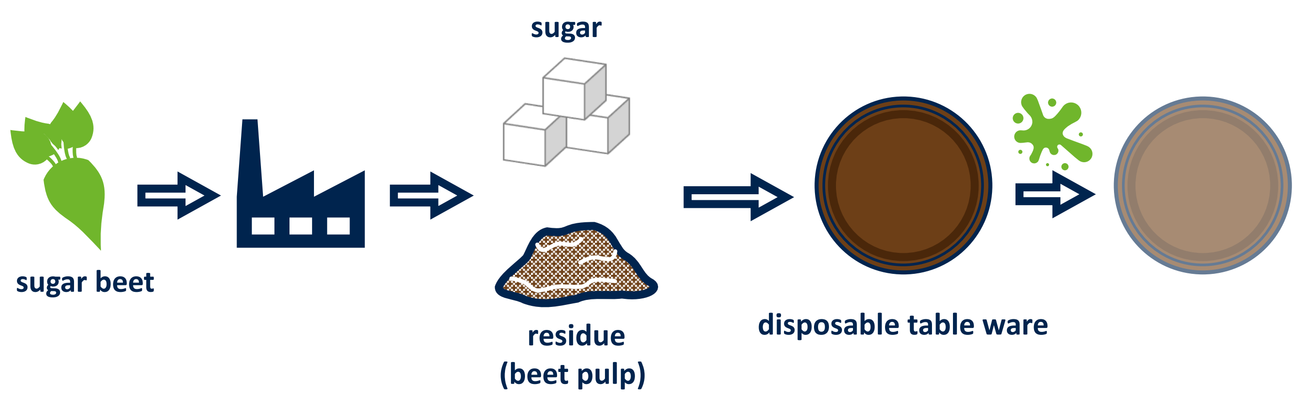

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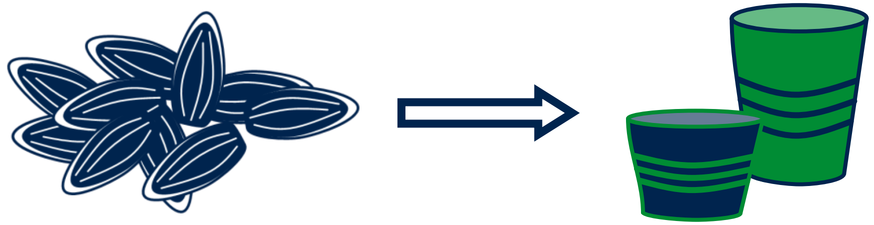
Sunflower seed shells as reinforcing filler material in biocomposites:

- Controlled material supply
- Not suitable for thermal recycling/usage -> **thermal resistance** as advantage for the processing
- Very good compatibility with **standard methods of plastics processing**

Application examples: flower pots, plant clips, clothes hangers

[adapted from: Golden Compound GmbH]



"Natural fibers enable a sustainable path for innovations that revolutionize industrial applications by combining strength and flexibility with renewability and biodegradability."

Discover – Develop – Connect

Your contact and partner regarding fiber-reinforced plastics

Tobias Göbel
SKZ – Das Kunststoffzentrum

transbib@skz.de

Self-check

True or false? Evaluate the following statements based on the content from the recent chapter (solutions are presented on the following slide).

(1) Natural fibers tend to be hydrophobic and can therefore be easily incorporated into any polymer matrix.

(2) Natural fibers are hygroscopic, meaning they tend to absorb moisture.

(3) The type and length of the fibers, as well as their orientation, determine the final strength of the material.

(4) Natural fibers can be used at all processing temperatures conventionally used for technical polymers.

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True or false? Evaluate the following statements based on the content from the recent chapter (solutions are presented on the following slide).

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False! Natural fibers are generally hydrophilic (polar). It may therefore be necessary to use adhesion promoters (dispersing agents) to improve the compatibility of the polymer matrix and the fiber.

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True! Unlike technical fibers, natural fibers tend to absorb moisture more readily and should therefore be dried before use.

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True! Natural materials can be suitable for different applications depending on the fiber length. Fibers that are too short and residual materials can be used as fillers (example: wood flour).

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False! When using natural fibers, their decomposition temperature of approx. 200 °C must be taken into account.

Note