Introduction to bioplastics and biocomposites

Dipl.-Ing. (FH) M. Neudecker
Prof. Dr.-Ing. A. Siebert-Raths
Prof. Dr.-Ing. H-J. Endres

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Introducing bioplastics

Raw material production → Polymer production → Processing → Use → End-of-Life
Agenda

1. Defining bioplastics
2. Bioplastics market data
3. Land use for bioplastics
4. Pros and cons of bioplastics
What are Bioplastics?

- "White" Biotechnology?
- Polymers from renewable resources?
- Degradable?
- Bio-degradable?
- Compostable?
- Oxodegradable?
- Water soluble?
- Natural fiber reinforced plastics?
- Opposite of conventional plastics?
- Sustainable?
- Renewable?
- Biogenic macromolecules?
- Bio-compatible?
The evolution of bioplastics

Generations of technical bioplastics

1st Bioplastics generation
- Starch polymers
- PHA

2nd Bioplastics generation
- Starch blends
- PLA
- PBAT
- PBS

3rd Bioplastics generation
- Bio-PA, Bio-PE, Bio-PET, PTT, Bio-PP

4th Bioplastics generation
- Residue utilization, bioeconomy

Focus on biodegradation (optimized properties)

Focus on biodegradation (bad properties)

Focus on bio-based, longevity, drop-ins

Focus on bio-based residues, longevity, drop-ins

Definition
Old and New Economy Bioplastics

Bioplastics

Old Economy
- Rubber
- Regenerated Cellulose
- Cellulose Acetates
- Linoleum
- etc.

New Economy
- Novel
  - PLA
  - PHA
  - PEF
  - Starch Blends
  - etc.
- Drop-Ins
  - Bio-PA
  - Bio-PE
  - Bio-PET
  - Bio-PP
  - etc.
But still, what are Bioplastics?

No new material group
→ classification in the class and the spectrum of plastics.

Classification into:

• Degradable petro-based bioplastics
• Degradable (predominantly) bio-based bioplastics
• Non-degradable, bio-based bioplastics

Facts about **bio-based** plastics:

• Renewable raw material base
• Raw material production for bio-based plastics requires less energy
• Novel material properties (except drop-ins)
• Various disposal options (material recycling, composting, climate-neutral energy recovery)
Definition of Bioplastics
“The bioplastics cross”

1. Cellulose Acetates
   Rubber, Casein…

2. Polyethylene
   Polypropylene
   Polyvinylchloride
   …

3. Polycaprolactone
   Polyvinyl alcohols
   Polyesters
   (PBAT, PBS, …)
   …

4. Polylactide,
   Starch blends,
   Cellulose Hydrates,
   Polyhydroxyalkanoate

5. Bio-PA, Bio-PE
   Bio-PET, PTT,…

Bio-degradable and bio-based

Bio-based

Bio-degradable

Bio-based non-degradable

Petro-based

Non-degradable

Source: H.-J. Endres, A. Siebert-Raths; Engineering Biopolymers, Carl Hanser-Verlag, 2011
Bioplastics applications

- **Biobased**: Products made from biological sources.
- **Bio-degradable**: Break down over time.
- **Petro-based**: Derived from petroleum.
- **Non-degradable**: Do not break down over time.

**Conventional plastics** are non-biodegradable and petro-based, while **bioplastics** can be bio-based or bio-degradable.
Market figures for bioplastics

New economy bioplastics production capacities 2017

61.3% bio-based/non-biodegradable
38.7% biodegradable

www.ifbb-hannover.de/de/facts-and-statistics.html
Market figures for bioplastics

New economy bioplastics production capacities 2022

59.5% bio-based/non-biodegradable
40.5% biodegradable

3.7% Bio-PP
18.7% PLA
8.8% Bio-PE
39.5% Bio-PET 30%
3.9% PTT
5.2% Biodegradable starch blends
12.0% Biodegradable polyesters* 
0.1% Cellulose derivatives *
0.7% Regenerated cellulose *

2017 = 2.27 million tons
2022 = 4.31 million tons
→ + 190%
Mainly pushed by PLA & Bio-PP

www.ifbb-hannover.de/de/facts-and-statistics.html
Market figures for bioplastics: Land area usage

Global land area = 13.4 billion ha = 100%
Agricultural area = 5 billion ha = 36.5%
Pasture = 3.5 billion ha = 26.1%
Arable land = 1.4 billion ha = 10.4%
Food & Feed = 1.24 billion ha = 9.25%
Biofuel = 53 million ha = 0.39%
Bioplastics 2022 = 1.04 million ha = 0.008%

www.ifbb-hannover.de/de/facts-and-statistics.html
Pros and cons of bioplastics

- Performance compared to conventional plastics
  → Same for the Drop-Ins / Others often comparable but some show weaknesses

- Special features
  → Biodegradability / new, special and unique material properties

- Feedstock
  → Independence from oil (for the bio-based) as a finite source of raw material

- Processing and material data basis
  → Is getting better but needs to be improved / Often only little or outdated information's

- Price
  → Competitive for some materials like PLA, but most are still more expensive
Thank you for your attention

Contact:

Dipl.-Ing. (FH) Marco Neudecker
Hochschule Hannover - University of Applied Sciences and Arts
IfBB – Institute for Bioplastics and Biocomposites
Faculty II – Mechanical and Bioprocess Engineering
Heisterbergallee 10A
30453 Hannover
Germany
Phone: +49 511 / 92 96 – 22 32
Fax: +49 511 / 92 96 – 99 28 23
E-mail: marco.neudecker@hs-hannover.de
Internet: http://www.ifbb-hannover.de
Processing

Raw material production → Polymer production → Processing → Use → End-of-Life
1. (Bio)Plastics Overview & market share
2. “The bioplastics processing challenges”
3. Processing bioplastics
4. Bioplastics processing hints & information’s
# Plastics Overview & Market Share

## The Two Categories of Plastics

### Thermoplastics
- Are a family of plastics that can be melted when heated and hardened when cooled. These characteristics, which lend the material its name, are reversible. That is, it can be reheated, reshaped and frozen repeatedly.

<table>
<thead>
<tr>
<th>Thermoplastic</th>
<th>Thermoplastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyethylene (PE)</td>
<td>Polycarbonate (PC)</td>
</tr>
<tr>
<td>Polypropylene (PP)</td>
<td>Poly methyl methacrylate (PMMA)</td>
</tr>
<tr>
<td>Polyvinyl-chloride (PVC)</td>
<td>Thermoplastic elastomers (TPE)</td>
</tr>
<tr>
<td>Polyethylene Terephthalate (PET)</td>
<td>Polyyarylsulfone (PSU)</td>
</tr>
<tr>
<td>Polystyrene (PS)</td>
<td>Fluoropolymers</td>
</tr>
<tr>
<td>Expanded polystyrene (EPS)</td>
<td>PEEK</td>
</tr>
<tr>
<td>ABS</td>
<td>POM</td>
</tr>
<tr>
<td>SAN</td>
<td>PBT</td>
</tr>
<tr>
<td>Polyamides (PA)</td>
<td>Etc.</td>
</tr>
</tbody>
</table>

### Thermosets
- Are a family of plastics that undergo a chemical change when heated, creating a three-dimensional network. After they are heated and formed, these plastics cannot be re-melted and reformed.

<table>
<thead>
<tr>
<th>Thermoset</th>
<th>Thermoset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyurethane (PUR)</td>
<td>Unsaturated polyester</td>
</tr>
<tr>
<td>Epoxy resins</td>
<td>Melamine resin</td>
</tr>
<tr>
<td>Vinyl ester</td>
<td>Silicone</td>
</tr>
<tr>
<td>Phenol - formaldehyde</td>
<td>Urea - formaldehyde</td>
</tr>
<tr>
<td>Phenolic resins</td>
<td>Acrylic resins</td>
</tr>
<tr>
<td>Etc.</td>
<td>Etc.</td>
</tr>
</tbody>
</table>

Source: [www.plasticseurope.org](http://www.plasticseurope.org)
Plastics Overview & market share

World and EU plastics production data

The world plastic* production almost reached 350 million tonnes in 2017.
Source: PlasticsEurope Market Research Group (PEMRG) / Conversio Market & Strategy GmbH

Europe ~ 19 %

Extrusion ~ 33 %
Injection molding ~ 16 %

Source: Ceresan study
Biolastics Overview & market share

New economy bioplastics production capacities by region 2022

~ 1.2 %* of world plastics production

Extrusion & injection molding are also the biggest applications for bioplastics

* Comparison between production data 2017 and production capacity data 2022

www.ifbb-hannover.de/de/facts-and-statistics.html
“The bioplastics processing challenges”
- The bad news (does not apply for drop-ins)

- Very limited material data available
- Limited processing knowledge available
- Limited information on pre-treatment / drying available
- Bioplastics need to provide "better" data if they want to displace traditional plastics in technical applications
- No/not enough bio-based additives available
- No/not enough bio-based master batches on the market
- Often higher material prices due to low production capacities
“The bioplastics processing challenges”
- The good news

- Bioplastics are also just plastics
- Processing them is normally as complex as switching from one plastics type to another, if there specific needs are observed
- They have very interesting an unique properties which can be beneficial
- Prices drop down with increasing production capacities and demand
Processing Bioplastics
- The bioplastics processing project

Manufacturing and Processing of Bio-Based Plastics and Establishment of a Competence Network within the Biopolymer Network maintained by the FNR (project management)

Task I
Determination Of Process Data

Task II
Knowledge Transfer

Task III
Integration Into The FNR Network
## Processing Bioplastics
- Thermoplastics – Extrusion

### Processing instructions

<table>
<thead>
<tr>
<th>Material</th>
<th>Processing instructions</th>
<th>processing temperature range [°C]</th>
<th>drying time</th>
<th>drying temperature [°C]</th>
<th>max. moisture [%]</th>
</tr>
</thead>
</table>
| PLA      | Pre-drying necessary → hydrolytic degradation  
At humidity > 0.025 % H2O influence of hydrolysis increases; the material becomes more flowable through chain degradation (low viscosity)  
Smaller fusing range  
Sharply-defined fusing zone  
Tiered temperature profile → Fast + gentle fusing (good for fibre incorporation)  
After extrusion → drying in crystalliser | 180–200 | 6 h | 80 | – |
| PLA blend | No general statement, as high number of combinations possible  
Dependent on miscibility, a relatively sharply-defined mixing zone should be chosen | | | | |
| PLLA     | Processing comparable with PLA | 190–220 | 6 h | 80 | < 0.025 |
| TPS      | No data available | | | | |
| TPS blend | No general statement, as high number of combinations possible  
TPS proportion leads to hydroscopic properties (moisture absorption) | | | | |

Source: © IfBB
Processing Bioplastics
- Thermoplastics – Injection Molding

- Rheological properties

- Screw geometry capacity
- Processing temperature efficiency
- Melting behavior plastification
- Solidification behavior sealing time
- Demolding behavior ejection
- Shrinkage behavior dimensional accuracy
- Weld line behavior multiple component
- Robustness processing
Processing Bioplastics
- Thermoplastics – Injection Molding

• Filling pressure vs. melt temperature

![Diagram showing various bioplastics and their filling pressure versus melt temperature.](chart)

- High viscosity cf. PC amorphous
- Increased viscosity cf. PBT filled
- Low viscosity cf. PA 6

In cooperation with UL TTC
Processing Bioplastics  
- Thermoplastics – Injection Molding

- Dimensional stability (Traffic light rating)  
  - Shrinkage and warpage of bioplastics

![Graph showing dimensional stability of various bioplastics processed according to ISO 294.](image)

Processed according to ISO 294

Flow direction (FD)
Cross-flow direction (CD)

Test plate 60 x 60 x 2 mm
Anisotropy factor FD/CD
Bioplastics processing hints & information´s
- List of contents

Bioplastics – chances and possibilities 4
Compounding 6
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Colouring 18
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Thermoforming behaviour 26
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Fibre production in melt spinning process 30
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Injection blow moulding and injection stretch blow moulding 36
Plastic extrusion 38

Processing Bioplastics

Go to: hs-h.de/processing-bioplastics
Further hints & information´s

www.materialdatacenter.com

<table>
<thead>
<tr>
<th>Producer</th>
<th>NatureWorks</th>
<th>PLA</th>
<th>NatureWorks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingneo™ 10361D</td>
<td>PLA</td>
<td>NatureWorks</td>
<td></td>
</tr>
<tr>
<td>Ingneo™ 2003D</td>
<td>PLA</td>
<td>NatureWorks</td>
<td></td>
</tr>
<tr>
<td>Ingneo™ 2506HP</td>
<td>PLA</td>
<td>NatureWorks</td>
<td></td>
</tr>
<tr>
<td>Ingneo™ 3001D</td>
<td>PLA</td>
<td>NatureWorks</td>
<td></td>
</tr>
<tr>
<td>Ingneo™ 3052D</td>
<td>PLA</td>
<td>NatureWorks</td>
<td></td>
</tr>
<tr>
<td>Ingneo™ 3100HP</td>
<td>PLA</td>
<td>NatureWorks</td>
<td></td>
</tr>
</tbody>
</table>

**Processing/Physical Characteristics**

- **Melt Flow Index, MFI**
  - Value: 80
  - Unit: g/10min
  - Test Standard: ASTM D 1238

- **Load**
  - Value: 2.16
  - Unit: kg

**Mechanical properties**

- **Tensile Strength at Yield**
  - Value: 62
  - Unit: MPa
  - Test Standard: ASTM D 638

- **FLEXURAL STRENGTH**
  - Value: 106
  - Unit: MPa
  - Test Standard: ASTM D 790

- ** Izod Impact notched, 1/8 in**
  - Value: 16
  - Unit: J/m
  - Test Standard: ASTM D 256

**Thermal properties**

- **Melting Temperature**
  - Value: 162
  - Unit: °C
  - Test Standard: ASTM D 3419

- **Glass Transition Temperature**
  - Value: 57.5
  - Unit: °C
  - Test Standard: ASTM E 1356

**Other properties**

- **Density**
  - Value: 1240
  - Unit: kg/m³
  - Test Standard: ASTM D 792

- **Processing Recommendation Injection Molding**
  - **Processing humidity**
    - Value: ±0.01%
  - **Mold temperature**
    - Value: 190 - 210 °C
  - **Feed temperature**
    - Value: 166 - 177 °C
  - **Zone 1**
    - Value: 182 - 193 °C
  - **Zone 2**
    - Value: 188 - 205 °C
  - **Nozzle temperature**
    - Value: 187 - 195 °C

Visit [www.materialdatacenter.com](http://www.materialdatacenter.com) for more information.
Further hints & information’s

Areas of expertise:

Bio-Based Plastics - Recommendations for Product Communication

hs-h.de/ifbb-areasofoexpertise

In action for biocomposites: Residual materials:

Processing of Bioplastics

hs-h.de/ifbb-productcommunication

hs-h.de/ifbb-residualmaterials

Marine Degradability of Bioplastics

Biopolymers – facts and statistics 2018:

hs-h.de/ifbb-marinedegradability

hs-h.de/factsandstatistics
Thank you for your attention

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Hochschule Hannover - University of Applied Sciences and Arts
IfBB – Institute for Bioplastics and Biocomposites
Faculty II – Mechanical and Bioprocess Engineering

Heisterbergallee 10A
30453 Hannover
Germany

Phone: +49 5 11 / 92 96 – 22 32
Fax: +49 5 11 / 92 96 – 99 28 23

E-mail: marco.neudecker@hs-hannover.de
Internet: http://www.ifbb-hannover.de