CIRCULAR ECONOMY

ZUKUNFTSWEISENDE POLYMERWERKSTOFFE
PIONEERING POLYMER MATERIALS

Prof. Dr.-Ing. Hans-Josef Endres
Hans-Josef Endres

Born on 17th of April 1966, married, 2 daughters (25 and 20)

Educational background:
- Dipl.-Ing. graduate of the Ruhr University Bochum, 1985, mechanical engineering, strong focus on material research
- PhD (Dr.-Ing.) received from University of Bochum, 1995

Professional experience and activities:
- 9 years of employment with industrial companies including a position as departmental director at Thyssen-Krupp, overseeing a staff of 230
- Professor at Hannover University of Applied Sciences & Arts, since 1999
- Director of the IfBB - Institute for Bioplastics and Biocomposites, 2011
- Head of Application Center for Wood Fiber and Composite Research, Fraunhofer Wilhelm-Klauditz-Institut WKI, 2012
- 2019 Professor at the Leibniz University of Hanover
- Director of the IKK – Institute of Plastics and Circular Economy
Main Research

Institute of Plastics and Circular Economy

- Material Development (plastics and bioplastics)
  - Plastics Processing
  - Recycling
- Material Testing
  - Polymer Analysis
- Sustainability Assessment
New Campus for Mechanical Engineering

- Located in Hanover Garbsen
- 20 Institutes
- About 1,000 employees
- About 5,000 students
Plastics as amazing and sustainable Materials

VW Golf 1

VW Golf 6

Source: VW, Peter Helmke
Plastics as amazing and sustainable Materials??
End-of-Life of plastics?

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

? + + + ?
Assessment of the plastics industry

Positive assessments in %

N=801 Broad Population, N=352 Young educated, N=355 Decision makers (in total 1,508)

Source: PlasticsEurope Germany 2019
What does Sustainability mean?

- Sustainability
- Ecological Sustainability
- Sustainable Materials
- Circular Economy
- Recycling
  - Mechanical
  - Chemical
  - Physico-chemical (Incineration)
Bioplastics

1. Cellulose Acetates
   Rubber, Casein…

2. Polyethylene
   Polypropylene
   Polyvinylchloride…

3. Polycaprolactone
   Polyvinyl alcohol
   Polyester (PBAT, PBS,..)

4. Polylactide, Starch blends,
   Cellulose Hydrates,
   Polyhydroxyalkanoate

5. Bio-PA, Bio-PE
   Bio-PET, PTT,…

Source: H.-J. Endres, A. Siebert-Raths;
Engineering Biopolymers, Carl Hanser-Verlag, 2011
How to measure Biobased

Carbon exists in form of 3 different isotopes: $^{12}\text{C}$, $^{13}\text{C}$ (stable) and $^{14}\text{C}$ (radioactive)

- Half-Life time of $^{14}\text{C}$ „only“ 5730 years
- Due to a continuous regeneration of $^{14}\text{C}$ in atmosphere the $^{14}\text{C}$ quota is nearly constant
- Photosynthesis $\rightarrow$ similar relationship of C-isotopes in plants
- Bio-based Polymers $\rightarrow$ similar relationship of C-isotopes in biopolymers
- Petrochemical raw materials and plastics contain no „young“ $^{14}\text{C}$, they consist out of „old“ $^{12}\text{C}$
Certification of biobased Contect (C14 Measurements, ASTM 6866)

DIN CERTCO

Vincotte
Biodegradability

Primary and ultimate degradation

Primary Degradation

Hydrolysis and enzymatic degradation

Microorganism \rightarrow Metabolic degradation

Oligomers and Monomers

Ultimate Degradation

CO₂ + H₂O + CH₄

Source: H.-J. Endres et al., Engineering Biopolymers, Carl Hanser, modified
Degradation Scenarios of Bioplastics

Degradation Scenarios

- Landfill
- Metabolization in organism
- Anaerobic digestion
- Decomposition in soil
- Ocean
- Beach
- River/Lake
- Clarification Plant
- Industrial Composting
- Domestic composting

Source: H.-J. Endres, unpublished
Old and New Economy Bioplastics

Old Economy

- Rubber
- Regenerated Cellulose
- Cellulose Acetates
- Linoleum

New Economy

- Novel
  - PLA
  - PHA
  - PBS
  - PBAT
  - Starch Blends
  - etc.
- Drop-Ins
  - Bio-PET
  - Bio-PE
  - Bio-PA
  - Bio-PUR
  - Bio-PP
  - etc.

Source: H.-J. Endres, unpublished
Recyclates
End of Life Options for Circular Economy

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

- Re-Use
- Mechanical or physo-chem. Rec.
- Chemical Recycling
- Aerobic / Anaerobic digestion

Source: Spierling et al. 2018
Circular Economy Players

- Machinery Manufacturers
- Converters
- Brand Owners
- Consumers
- Recyclers
- Waste Collection Systems
- Designer
- Material Suppliers

Circular Economy
Circular Thinking within the entire Value Added Chain

- Design for Recyclates
- Design for Recycling
- Waste Separation by Consumer
- Waste Collection, Waste Logistic
- Development of Recycling Processes
- Advanced Recycling Machines
- Extension of Characterization of Recyclates
- Internationalization of Terminology and Definitions
- Supply chains for Recyclates
What do we need? - Design for Recycling

Maximization of Processing and Utilization Performance

Design for Recycling

(Product-)Design for Recyclates
Closing the Loops

Source: European Bioplastics, modified
Bioplastics - End of Life Options?
End of Life Options

- Metabolization in organism
- Anaerobic digestion (→ Bio-methane)
- Carbon-Neutral Incineration
- Landfill
- Litter

Mechanical Recycling

- Chemical Recycling
- Marine degradation
- Industrial Composting
- Domestic composting

Decomposition in soil

Biopolymer product

Source: H.-J. Endres, A. Siebert, A.-S. Kitzler
Biopolymers – a discussion on end of life options
Bioplastics Magazine 01/08
Waste treatment

H.-J. Endres, A. Siebert-Raths, Engineering Biopolymers, Carl Hanser Verlag 2011
Gravimetrische Analysen zum Kunststoffabbau werden durch Aufwuchse auf den Proben stark verfälscht.

Beispiel: Mittels CT können Proben zerstörungsfrei in 3D dargestellt werden. Dies ermöglicht es, den Aufwuchs aus der Analyse auszuschließen und ausschließlich die volumetrische Abnahme des Kunststoffes zu erfassen.

CT-Aufnahme
Transformation to biogas

Prüfung in einer Biogasbatch-Anlage nach VDI-Richtlinie 4630
Einwaage der Biopolymerproben 300g
ots: organische Trockensubstanz

Calorific values of different (bio)plastics

Source: H.-J. Endres, A. Siebert-Raths, Engineering Biopolymers, Carl Hanser Verlag 2011
## Tendencies of LCA Impact Categories of Bioplastics

<table>
<thead>
<tr>
<th>Impact category</th>
<th>Reason on the part of Biopolymers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Warming Potential</td>
<td>CO₂-uptake</td>
</tr>
<tr>
<td>Energy demand</td>
<td>Often in correlation with GWP</td>
</tr>
<tr>
<td>Abiotic Depletion Potential</td>
<td>Bio-based</td>
</tr>
<tr>
<td>Humantox</td>
<td>Tendency advantage due to savings in fossil energy less combustion processes</td>
</tr>
<tr>
<td>Ecotox</td>
<td>No tendency, very specific, savings in conventional substance releases vs. sub. from pesticides (field technique)</td>
</tr>
<tr>
<td>Photosmog Potential</td>
<td>No tendency, very specific, savings in use of conv. energy processes and substances vs. harvesting proc. (burning)</td>
</tr>
<tr>
<td>Acidification Potential</td>
<td>Tendency disadvantage, if agrarian products are used (fertilizers) and especially with harvest burnings</td>
</tr>
<tr>
<td>Eutrophication Potential</td>
<td>Tendency disadvantage, if agrarian products are used (fertilizers) and especially with harvest burnings</td>
</tr>
<tr>
<td>Land use</td>
<td>Agricultural land for biomass production needed</td>
</tr>
<tr>
<td>Water use</td>
<td>Additionally to process water, also cultivation water needed</td>
</tr>
</tbody>
</table>

Source: IfBB / PE INTERNATIONAL 2014
### Impact categories

<table>
<thead>
<tr>
<th>Impact category</th>
<th>Impact category Indicator</th>
<th>Unit</th>
<th>Characterization model</th>
<th>Robustness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate change, total 1)</td>
<td>Radiative forcing as global warming potential (GWP100)</td>
<td>kg CO2 eq</td>
<td>Baseline model of 100 years of the IPCC (based on IPCC 2013)</td>
<td>I</td>
</tr>
<tr>
<td>Ozone depletion</td>
<td>Ozone Depletion Potential (ODP)</td>
<td>kg CFC-11 eq</td>
<td>Steady-state ODPs as in (WMO 2014 + integrations)</td>
<td>I</td>
</tr>
<tr>
<td>Human toxicity, cancer 2)</td>
<td>Comparative Toxic Unit for humans (CTUh)</td>
<td>CTUh</td>
<td>USEtox model 2.1 (Fankte et al, 2017)</td>
<td>III</td>
</tr>
<tr>
<td>Human toxicity, non-cancer 2)</td>
<td>Comparative Toxic Unit for humans (CTUh)</td>
<td>CTUh</td>
<td>USEtox model 2.1 (Fankte et al, 2017)</td>
<td>III</td>
</tr>
<tr>
<td>Particulate matter</td>
<td>Impact on human health</td>
<td>disease incidence</td>
<td>PM method recomended by UNEP (UNEP 2016)</td>
<td>I</td>
</tr>
<tr>
<td>Ionising radiation, human health</td>
<td>Human exposure efficiency relative to U\textsubscript{235}</td>
<td>kBq U\textsubscript{235} eq</td>
<td>Human health effect model as developed by Dreicer et al. 1995 (Frischknecht et al, 2000)</td>
<td>II</td>
</tr>
<tr>
<td>Photochemical ozone formation, human health</td>
<td>Tropospheric ozone concentration increase</td>
<td>kg NMVOC eq</td>
<td>LOTOS-EUROS model (Van Zelm et al, 2008) as implemented in ReCiPe 2008</td>
<td>II</td>
</tr>
<tr>
<td>Acidification</td>
<td>Accumulated Exceedance (AE)</td>
<td>mol H+ eq</td>
<td>Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)</td>
<td>II</td>
</tr>
</tbody>
</table>

1) The indicator “Climate Change, total” is constituted by three sub-indicators: Climate Change, fossil; Climate Change, biogenic; Climate Change, land use and land use change.

Source: EU 2019
## Impact categories

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<th>Impact category</th>
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<th>Unit</th>
<th>Characterization model</th>
<th>Robustness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eutrophication, terrestrial</td>
<td>Accumulated Exceedance (AE)</td>
<td>mol N eq</td>
<td>Accumulated Exceedance (Seppälä et al. 2006, Posch et al. 2008)</td>
<td>II</td>
</tr>
<tr>
<td>Eutrophication, freshwater</td>
<td>Fraction of nutrients reaching freshwater end compartment (P)</td>
<td>kg P eq</td>
<td>EUTREND model (Struijs et al. 2009) as implemented in ReCiPe</td>
<td>II</td>
</tr>
<tr>
<td>Eutrophication, marine</td>
<td>Fraction of nutrients reaching marine end compartment (N)</td>
<td>kg N eq</td>
<td>EUTREND model (Struijs et al. 2009) as implemented in ReCiPe</td>
<td>II</td>
</tr>
<tr>
<td>Ecotoxicity, freshwater ²)</td>
<td>Comparative Toxic Unit for ecosystems (CTUₜₑ)</td>
<td>CTUₑ</td>
<td>USEtox model 2.1 (Fankte et al., 2017)</td>
<td>III</td>
</tr>
<tr>
<td>Land use</td>
<td>Soil quality index ³)</td>
<td>Dimensionless (pt) kg biotic production kg soil m3 water m3 groundwater</td>
<td>Soil quality index based on LANCA (Beck et al. 2010 and Bos et al. 2016)</td>
<td>III</td>
</tr>
<tr>
<td>Water use</td>
<td>User deprivation potential (deprivation-weighted water consumption)</td>
<td>m3 world eq</td>
<td>Available WAter REMaining (Aware) as recommended by UNEP, 2016</td>
<td>III</td>
</tr>
<tr>
<td>Resource use, minerals and metals</td>
<td>Abiotic resource depletion (ADP ultimate reserves)</td>
<td>kg Sb eq</td>
<td>CML 2002 (Guinée et al., 2002) and van Oers et al. 2002.</td>
<td>III</td>
</tr>
<tr>
<td>Resource use, fossils</td>
<td>Abiotic resource depletion – fossil fuels (ADP-fossil) ²⁰)</td>
<td>MJ</td>
<td>CML 2002 (Guinée et al., 2002) and van Oers et al. 2002</td>
<td>III</td>
</tr>
</tbody>
</table>

²) Toxicity indicators also have three subindicators but only the sum of the three shall be reported

³) This index is the result of the aggregation, performed by JRC, of the 4 indicators provided by LANCA model as indicators for land use.

Source: EU 2019
How can sustainability be measured?

LCSA = LCA + SLCA + LCE

- Environmental: Life Cycle Assessment
- Social: Social Life Cycle Assessment
- Economic: Life Cycle Economics

Source: BiNa 2018
How can sustainability be measured?

- Climate change
- Resource consumption
- Water consumption
- Acidification
- Eutrophication
- Summer smog
- Land use/Biodiversity
- Toxicity

- Environment

- Costs
- Price
- Perspective (Customers/Producers)

- Economic

- Social

- Child labour
- Accident risks
- Qualification

Source: BNa 2018
Sustainable Development Goals (SDGs)

1. NO POVERTY
2. ZERO HUNGER
3. GOOD HEALTH AND WELL-BEING
4. QUALITY EDUCATION
5. GENDER EQUALITY
6. CLEAN WATER AND SANITATION
7. AFFORDABLE AND CLEAN ENERGY
8. DECENT WORK AND ECONOMIC GROWTH
9. INDUSTRY, INNOVATION AND INFRASTRUCTURE
10. REDUCED INEQUALITIES
11. SUSTAINABLE CITIES AND COMMUNITIES
12. RESPONSIBLE CONSUMPTION AND PRODUCTION
13. CLIMATE ACTION
14. LIFE BELOW WATER
15. LIFE ON LAND
16. PEACE, JUSTICE AND STRONG INSTITUTIONS
17. PARTNERSHIPS FOR THE GOALS

Source: United Nations 2020
Contact

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