Plastics in the Circular Economy

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Secondary Vocational Education
Sustainable Chemical Technology
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NHL Stenden University of Applied Sciences: history

• Formerly Hogeschool Drenthe (with locations in Emmen, Meppel, and Assen).
• Merger (01-01-2008) with CHN, Christelijke Hogeschool Nederland (Leeuwarden).
• Formation of Stenden University of Applied Sciences.
• Merger (01-01-2018) with NHL, Noordelijke Hogeschool Leeuwarden (Leeuwarden).
• Formation **NHL Stenden University of Applied Sciences**.
NHL Stenden: some key data

- 24,000 students
- 90+ student nationalities
- 2,000 academic staff
- 15% international students
- Multi-campus university

- 14 academies
- 44 professorships
- 12 associate's degrees
- 73 bachelor's degrees
- 51 minors
- 17 master's degrees
NHL Stenden University of Applied Sciences: locations

Leeuwarden, Groningen, Assen, Meppel, Emmen
NHL Stenden has branch campuses abroad (International Hospitality Management, International Business Administration, Tourism Management, and Disaster Management).

**Bali:**

**Bangkok:**

**Quatar:**

**Zuid-Afrika:**
Green PAC: Center of Expertise (CoE)

- Cooperation with Hogeschool Windesheim (Zwolle): Green PAC (CoE).
- Applied and practice-oriented research.
- Topics:
  - Composites and biocomposites.
  - 3D printing (FDM en SLA).
  - Bioplastics (biobased and/or biodegradable).
  - Fibers and yarns.
  - Recycling (mechanical- or chemical recycling of plastics).
- iLAB, Innovation Laboratory in Zwolle (located on the Polymer Science Park) and in Emmen (located on the Emmtec Industry & Business Park).
- COCI, Centre of Open Chemical Innovation in Emmen (located on the Emmtec Industry & Business Park).
Origin of plastics

Plastics are made from oil.
Plastics and polymers

Ethylene:

```
H       H
\|      \|
C-C     C=C
\|      \|
H       H
```

Polymerization:

```
R-O-C-C-C-C-C-C-C-C-C-C-C-C-C-C-O-R
H   H   H   H   H   H   H   H   H   H   H
```

Or more simply:

```
\( \left( \begin{array}{c}
H \\
H
\end{array} \right) \) \( n \) = a very large integer
Amorphous vs. crystalline

Polymers

Thermoplastic
- Amorphous
- (Semi)-crystalline

Elastomer (rubber)

Thermoset
PlasticsEurope – plastics: global production

Plastics* production is stable in Europe and grows globally

Weight Titanic: 52,310 ton

5945 Titanics!!!
### Structure of polymers

**All carbon backbone vs. heteroatom backbone**

<table>
<thead>
<tr>
<th>Plastics</th>
<th>C-C backbone</th>
<th>Heteroatoms in backbone</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE</td>
<td>![PE structure]</td>
<td>![PET structure]</td>
</tr>
<tr>
<td>PP</td>
<td>![PP structure]</td>
<td>![PU structure]</td>
</tr>
<tr>
<td>PS</td>
<td>![PS structure]</td>
<td>![PVC structure]</td>
</tr>
<tr>
<td>PVC</td>
<td>![PVC structure]</td>
<td>![PET structure]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>fraction of total European demand [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE</td>
<td>29.6</td>
</tr>
<tr>
<td>PP</td>
<td>18.9</td>
</tr>
<tr>
<td>PS</td>
<td>7.1</td>
</tr>
<tr>
<td>PVC</td>
<td>10.4</td>
</tr>
<tr>
<td>PET</td>
<td>6.9</td>
</tr>
<tr>
<td>PU</td>
<td>7.4</td>
</tr>
</tbody>
</table>
PlasticsEurope – plastics: applications

Plastics meet the needs of a wide variety of markets

Distribution of European plastics demand by segment in 2014

<table>
<thead>
<tr>
<th>Segment</th>
<th>Demand Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>3.4%</td>
</tr>
<tr>
<td>Electrical &amp; electronic</td>
<td>5.7%</td>
</tr>
<tr>
<td>Automotive</td>
<td>8.6%</td>
</tr>
<tr>
<td>Building &amp; construction</td>
<td>20.1%</td>
</tr>
<tr>
<td>Packaging</td>
<td>39.5%</td>
</tr>
<tr>
<td>Others*</td>
<td>22.7%</td>
</tr>
</tbody>
</table>

* Others: include sectors such as consumer and household appliances, furniture, sport, health and safety

Source: PlasticsEurope (PEMRD) / CIRCIT / myCargi
European plastics converter demand by segments and polymer types in 2016
Data for EU28+NO/CH.
In 2014 plastics recycling and energy recovery reached 69.2%.

In 2014, 25.8 million tonnes of post-consumer plastics waste ended up in the waste upstream, 69.2% was recovered through recycling and energy recovery processes while 30.8% still went to landfill.

- **Recycling**: 29.7%
- **Energy recovery**: 39.5%
- **Landfill**: 30.8%

25.8 m t of post-consumer plastics waste

Treatment for post-consumer plastics waste in the EU28 + Norway and Switzerland

Source: Consulus
PlasticsEurope – plastics recycling trends

Since 2006 recycling and energy recovery have increased

The annual average of post-consumer plastics waste generation from 2006 to 2014 is 25 million tonnes

Landfill: -38%
Energy recovery: +46%
Recycling: +64%

2006-2014 progress of recycling and energy recovery
Source: Cenlastic
Linear economy vs. circular economy

Lineaire economie  Keteneconomie met recycling  Circulaire economie

Grondstoffen  Grondstoffen  Duurzame productie
Productie  Productie  Recycling
Gebruik  Gebruik  Duurzaam gebruik
Restafval  Restafval  Recycling

Van Afval Naar Grondstof

Invulling programma Van Afval Naar Grondstof (Mansveld, 28 januari 2014)
The linear 'Take - Make - Dispose' system, which depletes natural resources and generates waste, is deeply flawed and can be productively replaced by a restorative model in which waste does not exist as such but is only food for the next cycle.

— Ellen MacArthur —
The New Plastics Economy: situatie 2050

WITH AN EXPECTED SURGE IN CONSUMPTION, NEGATIVE EXTERNALITIES RELATED TO PLASTICS WILL MULTIPLY

2014

2050

PLASTICS PRODUCTION

311 MT

1,124 MT

RATIO OF PLASTICS TO FISH IN THE OCEAN (BY WEIGHT)

1/5

>21

PLASTICS' SHARE OF GLOBAL OIL CONSUMPTION

6%

20%

PLASTICS' SHARE OF CARBON BUDGET

1%

15%

1. Assuming a modest growth (+2% to +4% per year) and no material production growth, the piracy of overall growth and a high-demand plastic. 2. Global oil demand is expected to rise from 34.2 billion dollars in 2014 to 57.2 billion dollars in 2025. 3. The 2014 estimate is based on a net increase in plastic waste recovery to 2014 to 2001. Carbon budgets are based on 1992-2014 IPCC assessments.

Note: This analysis is based on data from a variety of sources, including the United Nations, the World Economic Forum, and various academic institutions.
THE NEW PLASTICS ECONOMY

1. CREATE AN EFFECTIVE AFTER-USE PLASTICS ECONOMY

- RECYCLING
- OTHER MATERIAL STREAMS

2. DRASTICALLY REDUCE THE LEAKAGE OF PLASTICS INTO NATURAL SYSTEMS & OTHER NEGATIVE EXTERNALITIES

3. DECOUPLE PLASTICS FROM FOSSIL FEEDSTOCKS

- RENEWABLY SOURCED VIRGIN FEEDSTOCK

DESIGN & PRODUCTION

USE

ENERGY RECOVERY

REUSE

*Source: Project Watermark analysis*
Bioplastics:

- Biobased: e.g. biobased PE, PET, PA, PTT
- Biodegradable: e.g. PLA, PHA, PBS, Starch blends
- Conventional plastics: e.g. PE, PP, PET
- Fossil-based: e.g. PBAT, PCL
Biobased plastics
Biobased or partially biobased durable plastics, such as biobased or partially biobased PE, PET or PVC, possess properties, which are identical to their conventional versions. These bioplastics are technically equivalent to their fossil counterparts; yet, they help to reduce a product’s carbon footprint. Moreover, they can be mechanically recycled in existing recycling streams.
**Bio-based & durable bioplastics 2017 vs. 2022**

- **PP**
- **PE**
- **PET**
- **PA**
- **PEF**
- **Others**

*Bio-based PP and PEF are currently in development and predicted to be available in commercial scale in 2020.*


More information: [www.bio-based.eu/markets](http://www.bio-based.eu/markets) and [www.european-bioplastics.org/market](http://www.european-bioplastics.org/market)
Biobased content
Companies with biobased bioplastics can either indicate the ‘biobased carbon content’ or the ‘biobased mass content’ of their products. As these units of measurement differ, the typical numeric percentage value will differ, too, and must be taken into account, especially when drawing comparisons.

A well-established methodology to measure the biobased carbon content in materials or products is the 14C-method (EU standard: CEN/TS 16137, corresponding US-standard: ASTM 6866). Certification schemes and derived product labels based on the European and the U.S. standard are available – for example by the Belgian certifier Vinçotte or German certifier DIN CERTCO.
**Biodegradable plastics**

The property of biodegradation does not depend on the resource basis of a material. This feature is directly linked to the chemical structure of the polymer and can benefit particular applications, in particular packaging. Biodegradable plastic types offer new ways of recovery and recycling (organic recycling). If certified compostable according to international standards such as the EN 13432 (preferably by an independent third party), these plastics can be composted in industrial composting plants.
Biodegradable bioplastics 2017 vs. 2022

Land use estimation for bioplastics 2017 and 2022

- Global land area: 13 billion ha = 100%
- Global agricultural area: 4.9 billion ha = 38%

GLOBAL AGRICULTURAL AREA

- Pasture: 3.3 billion ha = 67%
- Arable land**: 1.4 billion ha = 29%
- Food & Feed: 1.24 billion ha = 25%
- Material use: 106 million ha = 2%
- Biofuels: 53 million ha = 1%

Bioplastics
- 2017: 0.82 million ha = 0.016%
- 2022: 1.03 million ha = 0.021%


* In relation to global agricultural area
** Including approx. 1% fallow land
Global production capacities of bioplastics 2017 (by material type)

- PET: 26.3%
- PA: 11.9%
- PEF*: 0.0%
- PE: 9.7%
- PP*: 0.0%
- Other (bio-based/non-biodegradable): 9.2%
- PBAT: 5.0%
- PBS: 4.9%
- PLA: 10.3%
- PHA: 2.4%
- Starch blends: 18.8%
- Other (biodegradable): 1.5%

**Total: 2.05 million tonnes**

*Bio-based PP and PEF are currently in development and predicted to be available in commercial scale in 2020.

More information: [www.bio-based.eu/markets](http://www.bio-based.eu/markets) and [www.european-bioplastics.org/market](http://www.european-bioplastics.org/market)
Global production capacities of bioplastics in 2017 (by market segment)

Total: 2.05 million tonnes in %

- Packaging (flexible & rigid): 58%
- Consumer goods: 11%
- Automotive & transport: 7%
- Building & construction: 7%
- Textiles: 6%
- Agriculture & horticulture: 5%
- Electrics & electronics: 4%
- Others: 2%

Global production capacities of bioplastics in 2017 (by region)

Total: 2.05 million tonnes

- Asia: 16
- South America: 18
- North America: 10
- Europe: 56
- Australia/Oceania: 0

*Production in Australia/Oceania is a small proportion relative to the global production capacity.

More information: [www.bio-based.eu/markets](http://www.bio-based.eu/markets) and [www.european-bioplastics.org/market](http://www.european-bioplastics.org/market)
Bioplastics: biobased PE

**Green Polyethylene Cycle**

1. **Sugarcane**
   - Sugarcane metabolizes CO2 to produce sucrose.

2. **Ethanol**
   - CH₃ – CH₂OH
   - At the mill, sugar juice and molasses are fermented and then distilled to produce ethanol.

3. **Ethylene**
   - CH₂ = CH₂
   - Through the process of dehydration, ethanol is transformed into ethylene.

4. **Green PE**
   - CH₂ = CH₂
   - Ethylene is polymerized in polyethylene in shared polymerization units.

5. **Final Products**
   - I’m Green™ Green Polyethylene is transformed into final products by the same processes and machinery of fossil PE.

6. **Recycling**
   - I’m green™ is recyclable in the same chain established for fossil PE (mechanics/incineration).
Bioplastics: biobased PE

1 Hectare of land produces 82.5 ton Sugar Cane
produces 7200 l Ethanol
produces 3 ton Green Ethylene
produces 3 ton Green PE
Bioplastics: biobased PE
Bioplastics: biobased PET

How is plantbottle™ PET Manufactured?

- Standard PET
  - Component A 70%
  - Component B 30%
- PlantBottle PET
  - Component A 70%
  - Component B 30%

PET resin

A: not commercial
B: commercial
Bioplastics: biobased PET
Bioplastics: biobased PET
Bioplastics: biobased PEF

Polyethylene terephthalate (PET)

Polyethylene Furanoate (PEF)
Bioplastics: biobased PET and PEF
Bioplastics: biobased PEF

YXY Technology

Dehydration → Oxidation → Polymerization

MMF (5-methoxy methyl fural)

FDCA

Methyl Levulinate

Plant based Feedstock

PEF
Bioplastics: biobased PEF

Moving to 100% green

- PET is the most widely used polyester made of PTA and EG
- Plantbottle launched in 2010 - PET with biobased EG and oil-based PTA
- PEF by Avantium: biobased FDCA + biobased EG = 100% green

![Diagram showing composition of PET, PTA, and FDCA with renewable and oil-based components.](image-url)
From corn to polymers and fibers

1. Harvesting the corn
2. Getting sugar from the corn
3. The fermenter: Turning sugar into a monomer
4. Turning monomers into polymers
5. Fibers and fabrics are created
Bioplastics: biobased PTT
Bioplastics: biobased PA6,10

Biomass Resources
- Castor oil plant
- Castor bean

Castor oil → HOOC(CH₂)₈COOH
Sebacic acid (SA  C:10)

Fossil Resources
- Hexamethylenediamine (HD  C:6)

H₂N(CH₂)₆NH₂ → PA610

Bio-based carbon content: approx. 60%

Property
- Heat Stable & low moisture adsorption
- Alkaline resistivity

Application
- Tooth Brush
Mit den fischer greenline Produkten ist fischer weltweit der erste Hersteller, der ein Sortiment an biobasierten Befestigungssystemen anbietet. Damit richten wir uns an Kunden, die während dem Bauen, Renovieren und Dekorieren auch beim Thema Befestigen großen Wert auf Nachhaltigkeit legen.
Bioplastics: compostable PBAT
Bioplastics: compostable PBAT

BASF
The Chemical Company

Ecovio®
www.ecovio.com
Bioplastics: compostable PBAT

- European standard EN 13432, Australian standard AS 4736
- European standard EN 13432
- American standard ASTM 6400
- Japanese standard GreenPla
- Home composting
- Chinese standard GB/T
Bioplastics: compostable PBAT
Bioplastics: compostable PBAT

**ecoflex® and ecovio®**

- **ecoflex®**
  - Based on fossil carbon
  - *partially renewable grades*
  - Compostable
  - Compound Enabler for renewable materials

- **ecovio®**
  - **ecoflex®** and PLA Compound
  - Compostable
  - 10-75% Renewable Content
  - Large range of properties and applications.

Original  2 weeks composting  4 weeks Composting
Bioplastics: compostable PBAT

ecoflex® and ecovio® BAG
- Biodegradation through microorganisms in compost
- 100% Compostable

“OXO-DEGRADABLE” BAG
- Composting not possible - Not biodegradable
- Fragmentation to PE fragments
- On exposure to strong light:
  - Only a small proportion is converted to CO₂ and biomass
  - Plastic fragments (PE)
  - Does not comply with AS 4736

POLYETHYLENE (PE) BAG
- Water
- CO₂ released
- Biomass

ecoflex® ecovio® Microorganisms Polyethylene (PE) Oxo-fragmentable PE PE fragments
Bioplastics: biodegradable PHA

**PHA**

- Bioplastic from the family of polyesters (e.g. PET)
- Good moisture and gas barrier
- Excellent film forming and coating properties
- Good biodegradability

![Diagram of PHA structures and corn](image)
Bioplastics: biodegradable PHA
Bioplastics: biodegradable PHA
Bioplastics: biodegradable PBS
**BioPBS. RENEWABLE. BIODEGRADABLE. THE EASY WAY TO CLEAN UP.**

BioPBS, solution for Compostable & Recyclable paper cups!

BioPBS coated paper samples (1 side & 2 side coating) are certified as recyclable by PTS (Papiertechnische Stiftung) according to PTS method RH021/97.

*Full certificates are available upon request.*
Bioplastics: biodegradable PBS

![Graph showing weight retention over time for different bioplastics including BioPBS FD92, BioPBS FZ91, PLA, and PBAT. The graph indicates decomposition rates in a 200 microns sheet sample in soil at 30°C/50%RH.](image-url)
Bioplastics: compostable PLA

Production of Polylactic Acid from Corn Starch

1. Corn Harvesting
2. Fermentation
3. Dehydration
4. Lactide Polymerisation

PLA vs. Other Plastics: Polystyrene, Polypropylene, Polyethylene Terephthalate

Water and energy consumed, and CO2 emitted to produce 1 pound (0.45 kg) of plastic:

- PLA: 31.1 l water, 7.37 kWh, 0.27 lbs CO2
- PET: 28.1 l water, 10.17 kWh, 0.28 lbs CO2
- PP: 19.5 l water, 9.25 kWh, 0.17 lbs CO2
- EPS: 17.7 l water, 11.17 kWh, 0.25 lbs CO2

If one person replaces all PP, PET, and EPS products he uses with PLA for one year, 68 lbs CO2 is not generated, worth of CO2 = 133 km.

- Save energy enough to light 2 homes for one day.
- Water enough to have 2 tub-baths.
- And 68% less Green House Gases are released.
Bioplastics: compostable PLA
Bioplastics: compostable PLA
Bioplastics: compostable PLA

100% COMPOSTABLE

CERTIFICATO N. P1084 DT N. 46.3

CERTIQUALITY

PRODOTTO CERTIFICATO

BIO BOTTLE

BIO BOTTLE
Bioplastics: compostable PLA