The New Age of Bio-based Polyamides – Current Trends and Uses

Moderator – Doug Weishaar, Evonik Corporation

1. Bio-based Polyamides - Current Trends and Overview:
   Doug Weishaar, Business Development Manager, Evonik Corporation

2. Monofilaments from Bio-based Polyamides:
   Enrique Mejía, General Manager, Proveedora Mexicana de Monofilamentos (PMM)

3. Sustainable Bio-Based Polyamide Fibers:
   Brendan McSheehy, Director of Innovation, Universal Fibers, Inc.

4. No strings attached - Rayon fiber reinforced bio-based polyamides:
   Benjamin Brehmer, Business Manager Biopolymers, Evonik Industries AG
Bio-based Polyamides: Current Trends and Overview
VESTAMID® Terra
High Performance Naturally
| a | Introduction to bio-based polyamides |
| b | Overview of product portfolio and supply chain |
| c | Commercial products and application fields |
| d | Ecological aspects |
| e | Conclusion |
Evonik is the creative industrial group from Germany, but is active worldwide

A worldwide presence

Production sites in 26 countries, active in over 100 countries

Source: World Congress on Industrial Biotechnology, Montreal, 2013
Evonik is focused on producing and achieving high-performance for petro and biopolymers.

The plastics pyramid

Petro-based Polymers
- PBT
- PES
- PMMA
- PPSU
- PFA

Bio-based Polymers
- PLA
- PHB
- PTT/3GT
- PA12
- PA11
- PA1010
- PA1012

High-performance
- PEEK
- PA12
- PA612
- PA46
- LCP

Engineering
- PMMA
- PPE
- PC
- POM
- PA6/66

Commodity
- PVC
- PS
- SAN
- PE-LD
- PE
- HDPE

Cost Driven
- PET
- PUR
- PP
- PE-HD

Performance Driven
- PE-UHD

Evonik’s Focus

~230Mton
~0.7Mton

Source: High Performance Polymers 2013
Capacity Source: PEMRG & European Bioplastics page
In the world of biopolymers there are four distinct categories which can be confusing.

### Biopolymer Categorical Breakdown

<table>
<thead>
<tr>
<th>Biomass-based Raw Materials</th>
<th>Biodegradable</th>
<th>Durable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biopolymers</td>
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</tr>
<tr>
<td>• biologically degradable and bio-based</td>
<td>• Resistant and bio-based</td>
<td>• Resistant and bio-based</td>
</tr>
<tr>
<td>• e.g. PLA, PHA</td>
<td>• e.g. PA1010, bio-PE</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Petroleum-based Raw Materials</th>
<th>Biodegradable</th>
<th>Conventional Polymers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biopolymers</td>
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<td>Conventional Polymers</td>
</tr>
<tr>
<td>• biologically degradable but petro-based</td>
<td>• 99% all polymers</td>
<td></td>
</tr>
<tr>
<td>• e.g. PBS, PCL</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Confusion still exists as the categories of biopolymer are not yet fully accepted / established:

- Most people and/or customers associated biopolymers with biodegradability.
- Many people and/or customers regard biopolymers as being recycled polymers.

**VESTAMID® Terra** falls under durable and bio-based.

High performance polymer based wholly or partially on renewable resources

→ Castor Bean
Fatty acid derivates can lead to a wide range of different polyamide building blocks

**Basic chemical derivation from fatty acids**

### Natural Fats and Oils

<table>
<thead>
<tr>
<th>Plant Species</th>
<th>Transesterification</th>
<th>Main Isolated Acid</th>
<th>Route 1</th>
<th>Route 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Castor Bean</td>
<td></td>
<td>Ricinoleic Acid</td>
<td>Transesterification</td>
<td>Transesterification</td>
</tr>
<tr>
<td>Peanut</td>
<td></td>
<td>Oleic Acid</td>
<td>Transesterification</td>
<td>Transesterification</td>
</tr>
</tbody>
</table>

### Examples: existing / theory

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<tr>
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<td>Peanut</td>
<td></td>
<td>Oleic Acid</td>
<td>Transesterification</td>
<td>Transesterification</td>
</tr>
</tbody>
</table>

**Route 1**
- Transesterification
  - Amination
  - Dehydration
  - Hydrogenation
  - Di-acid
    - single acid chain
    - Dimer Acid
      - double acid chain
    - Di-amine
      - double amine end-groups
  - Polymerization
  - AABB Polyamide
  - e.g. PA1010

**Route 2**
- Transesterification
  - Caustic oxidation
  - Thermolysis
  - Sebacic Acid
    - Octanedicarboxylic acid
  - Undecenoic Acid
    - 10-undecenoic acid
  - Azellic Acid
    - 1,7-nonanediolic acid
  - Nonanoic Acid
    - 1-octanediolic acid
  - Polymerization
  - AB Polyamide
  - e.g. PA11
  - e.g. PA99
  - e.g. PA10

Source: World Congress on Industrial Biotechnology, Montreal, 2013
Castor bean and castor oil are the common source for all biopolyamides like AABB’s

Supply chain of castor bean products and derivatives

<table>
<thead>
<tr>
<th>Others</th>
<th>Castor Bean/Oil</th>
<th>Monomers</th>
<th>Polymers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sebacic Acid: 75 Mton</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Castor Oil: 700 kton</td>
<td>Oilseed: ~1.5 Mton</td>
<td>Undecenoic Acid: 25 kton</td>
<td>Biopolyamides: ~50 kton</td>
</tr>
<tr>
<td>Castor Oil: ~900 kton</td>
<td></td>
<td>Sebacic Acid: 100 kton</td>
<td></td>
</tr>
</tbody>
</table>

- **Heptaldehyde**
- **Meal/Cake**
- **Lubricants**
- **Glycerin**
- **2-Octanol**
- **Polyester / ols**
- **Plasticers**
- **Lubricants**

**Castor Beans** *Ricinus Comminus*

**Castor Oil** *Triacylglycerol*

**Ricinoleic Acid** 12-Hydroxyoctadec-9-enoic acid

**Undecenoic Acid** 10-undecenoic acid

**Sebacic Acid** 1,8-octanedicarboxylic acid

**DMDA** Decamethylene diamine

**VESTAMID® Terra**

*VESTAMID® Terra* represents one of the many castor oil derivatives

Source: High Performance Polymers 2013
VESTAMID® Terra product line is based on a combination of different monomers.

### Diamine (AA)
- **C6** H: Hexamethylene Diamine
  
  \[
  \text{H}_2\text{N} \quad \text{H}_2\text{N} \quad \text{NH}_2 \quad \text{NH}_2
  \]

- **C10** D: Decamethylene Diamine
  
  \[
  \text{H}_2\text{N} \quad \text{H}_2\text{N} \quad \text{NH}_2 \quad \text{NH}_2
  \]

### Diacid (BB)
- **C10** S: Sebacic Acid
  
  \[
  \text{H}_2\text{N} \quad \text{H}_2\text{N} \quad \text{NH}_2 \quad \text{NH}_2
  \]

- **C12** D: Dodeconioic Diacid
- **D-G**: Triple D-A (Bio-route)

### Bio-based Monomers
- C10 Diamine “D”
- C10 Diacid “S”
- C12 Diacid “D-G”

### PA610 (HS); PA612 (D); PA1010 (DS); PA1012 (DD); PA1012 (DD-G); PA10T (DT)
The synthesis of VESTAMID® Terra HS is based both on renewable and fossil feedstocks.

**Monomer**
- Crude oil
- Naphtha
- C4-monomers
- Butadiene
- Butane-dinitrile
- Hexamethylene diamine

62% bio-renewable

**Certified:**
- Castor oil
- Ricinus communis
- Linoleic methyl ester + glycerine
- Sebacic acid + Isooctanol

**Polymer**
VESTAMID® Terra HS
Polyamide 610

Source: High Performance Polymers 2013
PA610 fills the performance gap between the commodity and the niche long-chain nylons

List of some key performance factors

• **VESTAMID® Terra HS** is heat stable and has a high stiffness

• **VESTAMID® Terra HS** is an option as an alternate material for PA 6 and PA 66, if a lower water absorption is required

• **VESTAMID® Terra HS** helps to reduce water absorption in blends with PA66 and PA6

• **VESTAMID® Terra HS** is close in its properties to PA 612 with a somewhat higher water absorption and lower chemical resistance

• **VESTAMID® Terra HS** cannot compete with PA 12 in terms of water absorption, chemical stability and impact resistance

Source: High Performance Polymers 2013
The synthesis of VESTAMID® Terra DS is based solely on renewable feedstocks.

Monomer

- Ricinus communis
- Castor oil
- Oleic methyl ester + glycerine
- Sebacic acid + Isooctanol
- C-10 Diamine

Polymer

VESTAMID® Terra DS
Polyamide 1010

100% bio-renewable Certified:
In many applications, PA1010 outperforms the niche long-chain nylons

List of some key performance factors

- **VESTAMID® Terra DS** shows higher heat stability and tensile modulus compared with PA12. PA1010 is especially suitable for highly GF-reinforced housing applications.

- **VESTAMID® Terra DS** base polyamide is highly translucent, potential for injection molding applications in sports industry

- **VESTAMID® Terra DS** powder coatings have high surface quality, gloss, and transparency. Potential for specialty coating and mini-coating powders

- **VESTAMID® Terra DS** is close in its properties to PA12. Water absorption, mechanical properties, and thermal properties are potential draw backs

- **VESTAMID® Terra DS** is a fully renewable alternative to PA612.

Source: High Performance Polymers 2013
The synthesis of VESTAMID® Terra DD(-G) can be based solely on renewable feedstocks.

Monomer:
- Ricinus communis
  - Castor oil
- Ricinoleic methyl ester + glycerine
- Sebacic acid + C-10 Diamine

Certified: 45% bio-renewable

Polymers:
- VESTAMID® Terra DD(-G)
- Polyamide 1012

Source: High Performance Polymers 2013

Dodecanoic Diacid is mostly produced via the fermentation of bituminous heavy oils.
In general PA1012 has the highest performance of all the bio-based polyamides

List of some key performance factors

- VESTAMID® Terra DD is highly translucent, flexible and ductile. It is especially suitable for decorative films, tubing applications and shoe soles.

- VESTAMID® Terra DD shows a very high impact strength and heat resistance. It is the best choice in applications were stiffness and impact strength is required.

- VESTAMID® Terra DD is a very good choice for the development of a bio based PEBA–grade.

- VESTAMID® Terra DD can replace PA11 in most applications.
- Introduction to bio-based polyamides
- Overview of product portfolio and supply chain
- Commercial products and application fields
- Ecological aspects
- Conclusion
The are three distant pathways to place VESTAMID® Terra biopolymers into the market

<table>
<thead>
<tr>
<th>Existing applications areas</th>
<th>Novel applications areas</th>
<th>Unique Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility</td>
<td>Substitution</td>
<td></td>
</tr>
<tr>
<td>• Tubing</td>
<td>• Filaments</td>
<td>Composites</td>
</tr>
<tr>
<td>• Airbrake</td>
<td>• Toothbrushes</td>
<td>• Toughener</td>
</tr>
<tr>
<td>• Liners</td>
<td>• Carpets</td>
<td>• Impact Modifier</td>
</tr>
<tr>
<td>Solar</td>
<td>• Sports</td>
<td>• Matrix</td>
</tr>
<tr>
<td>• Backpanels</td>
<td>• Shoe Soles</td>
<td></td>
</tr>
<tr>
<td>• Barrier Sheets</td>
<td>• Outdoor Apparel</td>
<td></td>
</tr>
<tr>
<td>Household</td>
<td>• Cosmetics</td>
<td>• Thin Walled</td>
</tr>
<tr>
<td>• Powder Coating</td>
<td>• Fine Powders</td>
<td>• Components</td>
</tr>
<tr>
<td>Cables</td>
<td>• Electronics</td>
<td>• Flowability</td>
</tr>
<tr>
<td>• Jacketing</td>
<td>• Casings</td>
<td>• Abrasion</td>
</tr>
</tbody>
</table>

Source: High Performance Polymers 2013
VESTAMID® *Terra* can be extruded as foils and films for decorative and barrier purposes.

**Extruded Films and Foils**
- Special attention towards grades with high purity and termination
- Transparent and colored films are possible

**Potential Industries**
- Photovoltaic
- Design
- Packaging

**Application Benefit**
- Scratch Resistance
- Cold Impact
- Barrier Properties
- Light Transmission
- High Reflection
- Environmentally Friendly

**Some Available Grades**

**Commercial**
- **LX9016**
  - High-viscosity blend
  - Texturable and printable
  - White and natural

**Developmental**
- **Terra DS20**
  - High-viscosity PA1010
  - Neat and terminated
- **Terra DD18**
  - Mid-viscosity PA1012
  - Neat and terminated

We care about even the thinnest applications.
Several product examples of extruded films and foils based on VESTAMID® Terra

<table>
<thead>
<tr>
<th>Industries Served</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Photovoltaic</td>
<td>Design</td>
</tr>
<tr>
<td>Reflective backsheets</td>
<td>Graphically appealing films</td>
</tr>
<tr>
<td>Flexible laminates</td>
<td>Ski laminates / surface</td>
</tr>
</tbody>
</table>
VESTAMID® Terra can be compounded with halogen-free flame retardant additives

Flame Retardant Grades (FR)
- Can be modified, stabilized and fiber reinforced, if needed
- Both injection and extrusion variants have been developed

Potential Industries
- Electronics
- Aeronautics
- Building and Infrastructure

Some Available Grades
Commercial
- Terra DS1680
  - Low-viscosity PA1010
  - Glassfiber reinforced
  - White and natural
- Terra DS1880
  - Mid-viscosity PA1010
  - Glassfiber reinforced
  - White and natural

Developmental
- Terra DS2280 (BS1512)
  - High-viscosity PA1010
  - No reinforcement

Application Benefit
- Thermal Stability
- V2 and partially V0*
- Thermal Insulation
- Low Water Uptake
- Mechanical Strength
- Environmentally Friendly

We care about avoiding the risks attributed to hazardous environments

Source: High Performance Polymers 2013

*According to UL94
Several product examples of the flame retardant grades of VESTAMID® Terra

<table>
<thead>
<tr>
<th>Industries Served</th>
<th></th>
<th></th>
<th>Building and Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronics</td>
<td>Aeronautics</td>
<td>Building and Infrastructure</td>
<td></td>
</tr>
<tr>
<td>Cable boxes and clips</td>
<td>Aircraft interior parts</td>
<td>Lamp housing</td>
<td></td>
</tr>
<tr>
<td>General housings</td>
<td></td>
<td></td>
<td>Cable trunking systems</td>
</tr>
</tbody>
</table>

Source: High Performance Polymers 2013
VESTAMID® Terra products can be reinforced using a variety of fibers and composite materials.

Fiber Reinforced Grades (GF/VF/CF)
- Can be reinforced with glass fiber, viscose fiber or carbon fiber
- Both injection and extrusion variants have been developed

Potential Industries
- Automotive
- Sports
- Building and Infrastructure

Application Benefit
- Mechanical Strength
- Weight Reduction
- Thermal Insulation
- Low Water Uptake
- Environmentally Friendly

Some Available Grades

Commercial
- Terra HS1850
  - Mid-viscosity PA610
  - 30% glassfiber reinforced
  - White and natural

Developmental
- Terra DS16-VF30
  - Low-viscosity PA1010
  - 30% rayon fiber reinforced
- CW1039 (DS18-CF30)
  - Mid-viscosity PA1010
  - 30% recycled carbon fiber

We care about supporting those elements under stress.
Several product examples of the fiber reinforced grades of VESTAMID® *Terra*

<table>
<thead>
<tr>
<th>Industries Served</th>
<th></th>
<th></th>
<th>Building and Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Automotive</strong></td>
<td><strong>Sports</strong></td>
<td><strong>Building and Infrastructure</strong></td>
<td></td>
</tr>
<tr>
<td>Housing cage</td>
<td>Shoe soles, studs</td>
<td>Window profiles and insulation</td>
<td></td>
</tr>
<tr>
<td>Quick connectors</td>
<td>Rackets and sticks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: High Performance Polymers 2013
VESTAMID® *Terra* pellets, when tailored, can create sustainable fibers and fabrics

**Multifilaments**
- Base grades and production recipes are specially tailored for different fiber applications

**Potential Industries**
- Carpet
- Reinforcement
- Textiles

**Application Benefit**
- Silky Touch & Appearance
- Low-Water Uptake
- Fast Drying Rate
- Chemical Resistance
- Mechanical Strength
- Environmentally Friendly

**Some Available Grades**

**Developmental**
- **Terra HS12X**
  - Ultralow-viscosity PA610
  - Different terminations available
- **Terra HS16X**
  - Mid-viscosity PA610
- **Terra DS14X**
  - Low-viscosity PA1010
  - Special termination recipe
- **Terra DS16X**
  - Mid-viscosity PA1010
  - Special termination recipe

We care about providing safe, hygienic and comfortable solutions
## Industries Served

<table>
<thead>
<tr>
<th>Carpet</th>
<th>Reinforcement</th>
<th>Textiles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tiles; micro tufted</td>
<td>Tire cord and carcasses</td>
<td>Sports apparel</td>
</tr>
<tr>
<td>Residential wall-to-wall</td>
<td>Lines and Strings</td>
<td>Bandages (USP* approved)</td>
</tr>
</tbody>
</table>

*United States Pharmacopeia (USP) Class VI material classification*
VESTAMID® Terra pellets, when tailored, can create sustainable fibers and strings

Monofilaments
- Base grades and production recipes are specially tailored for different filament applications

Potential Industries
- Bristles
- Strings
- Filters

Application Benefit
- Silky Touch & Appearance
- Low-Water Uptake
- Fast Drying Rate
- Chemical Resistance
- Bonding Ability
- Environmentally Friendly

Some Available Grades

Commercial
- Terra DS16
  - Mid-viscosity PA1010
  - Standard termination recipe
- Terra HS16
  - Mid-viscosity PA610
  - Standard termination recipe

Developmental
- Terra BS1396 (DS23)
  - Ultra-high-viscosity PA1010
- Terra HS18
  - Mid-viscosity PA610

We care about providing safe, hygienic and comfortable solutions
Several product examples of monofilament extruded products from VESTAMID® *Terra*

### Industries Served

<table>
<thead>
<tr>
<th>Bristles</th>
<th>Strings</th>
<th>Filters</th>
</tr>
</thead>
</table>
| **Toothbrush** | **Racket Sports** | **Paper Machine Fabrics**  
General cleaning bristles |  
Lines and strings | Tee or Coffee Filters  
Membranes for Hot-air Balloons |
VESTAMID® Terra with its high peak temperature is suitable for many extrusion applications

Extrusion Grade

- High viscosity grades usually accompanied with special additives
  Such as: impact modifiers, plasticizers, thermal stabilizers, etc.

Potential Industries

- Automotive Tubing
- Cable Jacketing
- Pipes

Application Benefit

- Cold Impact Strength
- Chemical Resistance
- Oil and Salt Resistance
- Burst Strength
- Flexibility
- Environmentally Friendly

Some Available Grades

Commercial

- Terra DS2210 (CW1082)
  - Rodent resistance jacketing
- Terra DS2230 (CW1078)
  - Stiff airbrake tubing
- Terra DD2230 (CW1120)
  - Flexible airbrake tubing
- HS22X-HI-H2
  - Operation at elevated temps
- X7070
  - Impact element based on Terra

We care about systematic quality for endless consistency
Several product examples of the extrusion grade of VESTAMID® Terra

### Industries Served

<table>
<thead>
<tr>
<th>Automotive Tubing</th>
<th>Cable Jacketing</th>
<th>Pipes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pneumatic (airbrake) lines</td>
<td>Rodent / ant resistant</td>
<td>Liners and tubes</td>
</tr>
<tr>
<td>Fluid (coolant, diesel, clutch) lines</td>
<td>Optical wire cables</td>
<td></td>
</tr>
</tbody>
</table>

Source: High Performance Polymers 2013
VESTAMID® Terra can be injection molded into a wide variety of parts and pieces

Injection Molding Grades
- Shrinkage and quality are monitored for long-term success
- Typically mid-viscosity grades with special additives and colors

Potential Industries
- Sports
- Small Components
- Automobile

Application Benefit
- Mechanical Strength
- Scratch Resistance
- High Flowability
- Heat Deflection
- Crystalline Formation
- Environmentally Friendly

Some Available Grades

Commercial
- LX9012
  - High-viscosity blend
  - Flexibility: “unbreakable”
  - Natural

Developmental
- Terra DS16
  - Mid-viscosity PA1010
  - Neat and terminated
- Terra DD18
  - Mid-viscosity PA1012
  - Neat and terminated

We care about aesthetically pleasant and technically sound products

Source: High Performance Polymers 2013
Several product examples of the injection molding grade of VESTAMID® *Terra*

<table>
<thead>
<tr>
<th>Industries Served</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sports</strong></td>
<td><strong>Small Components</strong></td>
</tr>
<tr>
<td>Shoe soles, liners</td>
<td>Accessories, optical / writing / time</td>
</tr>
<tr>
<td>Winter sport boots</td>
<td>Electronic housings</td>
</tr>
</tbody>
</table>

Source: High Performance Polymers 2013
VESTAMID® Terra in its powder form is marketed under the label VESTOSINT® Terra

Powders
- Utilizes unique powder precipitation and fine grinding technology
- Can be combined with special additives

Potential Industries
- Cosmetics
- Composites / Coatings
- Additive Manufacturing*

Application Benefit
- Narrow Particle Distribution
- High Surface Area
- High Melting Point
- High Purity
- Chemical Resistance
- Environmentally Friendly

Some Available Grades

Commercial
- VESTOSINT® Terra 9157, 9158, 9159, 9161, 9162
  - Various powder systems
  - Size: 10 – 55 µm
- Tegolon Eco 1010
  - Cosmetic fine powder
  - Size: 10 µm

Developmental
- Z2640, Z2641
  - Various fine powders
  - Size: 10 – 20 µm

We care about protecting valuables against the elements

Source: High Performance Polymers 2013

*under development and could form integral part of potential powder systems
Several product examples of application based on the fine powder VESTOSINT® *Terra*

<table>
<thead>
<tr>
<th>Industries Served</th>
<th></th>
<th>Additive Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cosmetics</td>
<td>Composites / Coatings</td>
<td></td>
</tr>
<tr>
<td>Crèmes as oil dispersant</td>
<td>Fluidizing bed coating</td>
<td>Rapid prototyping, design objects, etc.</td>
</tr>
<tr>
<td>Sunscreens and moisturizers</td>
<td>Epoxy toughener</td>
<td></td>
</tr>
</tbody>
</table>

Source: High Performance Polymers 2013
VESTAMID® Terra grades designed for customer electronics are marketed as VESTAMID® eShell

High Flow Fiber Reinforced Grades
• Utilizes special fiber grades which are tailored for high flowability
• Achieves ultra-thin structures with low warping potential

Potential Industries
• Smartphone
• Tablet
• Laptop

Application Benefit
• Superior Flowability
• Extraordinary Stiffness
• Impact Resistance
• Crack Resistance
• Temperature Profile
• Environmentally Friendly

Some Available Grades
Commercial
• eShell CW1095
  • Very-low-viscosity PA1010
  • High degree of glass fiber
  • Tuned for impact
• eShell CW1224
  • Low viscosity PA10T
  • High degree of glass fiber
  • Tuned for stiffness
• eShell CW1226
  • Low viscosity PA10T
  • High degree of glass fiber
  • Flame retardant (V0)

We care about designing products to meet your most challenging vision
Several product examples of applications based on the reinforced VESTAMID® eShell grades

<table>
<thead>
<tr>
<th>Industries Served</th>
<th>Smartphone</th>
<th>Tablet</th>
<th>Laptop</th>
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<tbody>
<tr>
<td>Exterior cover</td>
<td><img src="image" alt="Exterior cover" /></td>
<td><img src="image" alt="Decorative molding" /></td>
<td><img src="image" alt="Metal insert molding" /></td>
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<tr>
<td>Internal frame</td>
<td><img src="image" alt="Internal frame" /></td>
<td><img src="image" alt="Battery cover" /></td>
<td><img src="image" alt="Housing" /></td>
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<tr>
<td>Decorative molding / composite overmold / housing</td>
<td><img src="image" alt="Interior frame" /></td>
<td><img src="image" alt="Battery cover" /></td>
<td><img src="image" alt="Housing" /></td>
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</tbody>
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Source: High Performance Polymers 2013
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<tbody>
<tr>
<td><strong>a</strong></td>
<td>Introduction to bio-based polyamides</td>
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<td><strong>b</strong></td>
<td>Overview of product portfolio and supply chain</td>
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<td>Conclusion</td>
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</table>
While an LCA has different impact categories, the scope defines the type of LCA.

The main (customer) focus is on the carbon footprint (CF).

---

**Impact categories**
- Feedstock
- Ozone depletion
- Eutrophication
- Acidification
- Global warming
- Production
- Ozone depletion
- Eutrophication
- Acidification
- Global warming
- Product use
- Ozone depletion
- Eutrophication
- Acidification
- Global warming
- End-of-life recycle/disposal

**Scope**
- Gate-to-gate
- Cradle-to-gate*
- Cradle-to-cradle/grave

*The cradle-to-gate is used for polymers to the point of compounding and pellet production.

**Source:** High Performance Polymers 2013

**LCA:** Life cycle assessment; CF: CO$_{2eq}$ over 100 years
The VESTAMID® Terra line has a lower carbon footprint than the petro-basednylons

Overview of carbon footprint of several polyamides

Source: High Performance Polymers 2013
Source: external publications, internal calculations with PE Int. Databank (Oct 2010)
Through downstream technical and procurement improvements, the CF can be further reduced.

Example: Improved LCA of VESTAMID® Terra HS (PA610)

CO₂-Equiv. / kg PA 610

The reduction of the carbon footprint (CF) can increase from 43% to 64%.

Hydropower can also be purchased for an additional reduction of around 25%.

Source: High Performance Polymers 2013
The ongoing debate about “food vs. fuel” should not affect biochemicals, let alone biopolymers

### Land use issues of biochemicals

- **Worldwide Arable Land**: 15 Mkm²
- **Worldwide Chemical Production**: 250Mton

Even if 100% of all chemicals were replaced by bio-based chemicals, only 3-4% of the global arable land would be needed

→ **Biochemicals do not affect food production**

When applying castor bean for chemicals:
- Toxic, not part of food chain
- Grows on arid to marginal lands
- Little agrochemicals needed
- Cultivated in areas for centuries

→ **Biochemicals from castor oil do not affect food production or cause land use change**

Source: High Performance Polymers 2013 / Endres, Kunststoffe 9/2011
Introduction to bio-based polyamides
Overview of product portfolio and supply chain
Commercial products and application fields
Ecological aspects
Conclusion
VESTAMID® Terra is

- Made from plant (bio-sourced)
- Environmental friendly
- Reduces global warming potential
- High performing
- Commercially available in diverse grades
- Competitive against existing polyamides