Mirel - PHA – The Story Continues
18 September 2012
Stan Haftka
Bio-Industrial Evolution

Through bioscience and engineering, we bring clean, sustainable, and economically viable solutions to the world in plastics, chemicals, and energy.
A World Leader in Industrial Biotechnology

- Founded 1992 by MIT professors and graduates
- Headquarters in Cambridge, MA, USA
- Biopolymer group in Lowell, MA, USA
- European business office in Cologne, Germany
- About 90 employees
- More than 700 patents issued and pending
- Shares traded on the NASDAQ
- Small company - entrepreneurial mindset
- The leader in PHA technology
Metabolix EU Office

- Offices at BioCampus Cologne
- Customer support functions for EUMEA
- Continue to use warehousing and logistics partner close to Amsterdam, Netherlands
## Broad-Based Renewables Platform

### Three Areas of Metabolix Focus

<table>
<thead>
<tr>
<th>Products</th>
<th>Fermentation</th>
<th>Crop Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biopolymers</td>
<td>PHA biopolymers • Injection molding • Films • Thermoforming • Additives, others</td>
<td>Industrial Chemicals • C4 chemicals (GBL/ BDO) • C3 chemicals (Acrylates) • C5 chemicals, others</td>
</tr>
<tr>
<td>Crop-Based</td>
<td>• High valued PHA traits in non-food crops • Initial crops: Oil seeds (camelina), Biomass (switchgrass, sugarcane)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Addressable Market</th>
</tr>
</thead>
<tbody>
<tr>
<td>Products</td>
</tr>
<tr>
<td>Crop Technology</td>
</tr>
<tr>
<td>Crop-Based</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Products</td>
</tr>
<tr>
<td>Crop Technology</td>
</tr>
<tr>
<td>Crop-Based</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Partnerships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Products</td>
</tr>
<tr>
<td>Crop Technology</td>
</tr>
<tr>
<td>Crop-Based</td>
</tr>
</tbody>
</table>
PHA Biopolymer Overview

- Research, production and sales of poly-hydroxyalkanoate (PHA) done by Metabolix
- PHA is an aliphatic polyester
- Mirel™ is the brand name for the bio-based and bio-degradable polymer family
- Mvera™ is the brand name for the Industrial compostable polymer family
Metabolix is Committed to PHA Biopolymers

- Produced targeted range of PHA grades with very high quality
- 50 ktons plant was shut-down early 2012
- More than 2 ktons of inventory
- Technology deployed and proven at industrial scale plant
- Future 10 ktons production in Leon, Northern Spain
- Partner company for Spain production: Antibioticos - background in industrial fermentation and pharmaceutical production
- Engineering project started 2012
- First materials for trial runs expected early 2013
- Large scale production expected later in 2013
How Mirel is Made

Biodegradable*
Mirel is biodegradable in natural soil and water environments, home and industrial composting facilities, where available.

Biobased
Starting with corn.

Corn Sugar
One of many products made from each kernel of corn, used as feedstock for Mirel.

Applications
Mirel can be processed on conventional equipment and used in everyday products.

Fermentation
A patented process, transforms the sugar into Mirel biopolymers.

Formulation
Mirel is compounded into resin pellets.
Compared to Conventional Plastics

- PHA is composed of renewable carbon (not fossil fuels)
- PHA biodegrades in a variety of environments
- PHA is moldable on conventional processing equipment
- PHA has mechanical properties comparable to PE
  - High heat distortion and usage temperature > 115ºC
  - Good barrier properties
  - Dishwasher safe
  - Suitable for gamma sterilization
  - Printable and colorable
  - Shelf stable
  - Weldable
### Biodegradable & Biodegradable Plastics

<table>
<thead>
<tr>
<th>Biodegradable</th>
<th>Compostable</th>
<th>Non-Biodegradable</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS</td>
<td>PBAT (Ecoflex)</td>
<td>Conventional Polymers: PE, PP, PS</td>
</tr>
<tr>
<td>PBSA</td>
<td>PGA (Kureha)</td>
<td></td>
</tr>
<tr>
<td>PCL</td>
<td>PVOH</td>
<td></td>
</tr>
<tr>
<td>PHA (Metabolix)</td>
<td>PLA (Ingeo)</td>
<td>Bio-PE (Braskem)</td>
</tr>
<tr>
<td>Cellulose</td>
<td></td>
<td>PA11, PA6, 10 PDO (Sorona DuPont)</td>
</tr>
<tr>
<td>Starch</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Petro-based**

**Bio-based**

**PHAs are both biobased and biodegradable**
Biodegradability of Mirel

- **Soil**
  - PHA biodegrades in typical soil
  - PHA does not require the high temperature and moisture cycle of hot composting facility in order to biodegrade (like PLA).

- **Marine or Fresh Water**
  - PHA biodegrades in low or cold temperatures.
  - PHA biodegrades in fresh or salt water marine environments.

- **Home or cold composting / Industrial composting systems**
  - PHA is different from many other bioplastics that require hot (industrial) composting systems. Yet, PHA will degrade here too!

- **Biodegradation is controlled by part thickness**
  - Thicker parts will take longer but will degrade over time.
## End of Life Options

<table>
<thead>
<tr>
<th>End of Life Options</th>
<th>Conventional Plastics</th>
<th>Mvera™</th>
<th>Mirel™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decomposing in Soil</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Dissolving in marine or fresh water</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Home or cold composting</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Anaerobic Digestion</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Industrial Composting</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Incineration with energy recovery</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Mechanical Recycling</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Landfill</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
OWS Testing: Evolution of the Disintegration in a Compost Environment

Mvera B5002 film @ 288 µm (11 mil) thickness

Source: Lab results from Organic Waste Systems, Belgium
Innovative and Sustainable Packaging

Marine Degradability

The Challenge:
- Test paper coated cups for marine degradation
- Program with Clovernook (Supplier to US Navy)

The Result: After one month in sea water, Mirel cup 95% degraded (only small portion of folded paper top lip remained); no residual Mirel remained. No other bio-plastic (or conventional plastic) close in performance.
## Wide Range Of Certifications

All commercial grades are in the process of further certifications

<table>
<thead>
<tr>
<th>Products</th>
<th>Certifications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Compostable EN 13432 / ASTM D6400</td>
</tr>
<tr>
<td>Biodegradable Film</td>
<td><img src="image" alt="ok_compost" /> <img src="image" alt="vinicotte" /> <img src="image" alt="home_compost" /> <img src="image" alt="mirel" /></td>
</tr>
<tr>
<td>P5001 (up to 282µm)</td>
<td>√</td>
</tr>
<tr>
<td>Compostable Film</td>
<td><img src="image" alt="m-vero" /> <img src="image" alt="mirel" /> <img src="image" alt="vinicotte" /> <img src="image" alt="mirel" /></td>
</tr>
<tr>
<td>B5002/8 (up to 288µm)</td>
<td>√</td>
</tr>
<tr>
<td>Injection Molding</td>
<td><img src="image" alt="mirel" /> <img src="image" alt="mirel" /> <img src="image" alt="vinicotte" /> <img src="image" alt="mirel" /> <img src="image" alt="vinicotte" /> <img src="image" alt="mirel" /></td>
</tr>
<tr>
<td>P1003 (up to 480µm)</td>
<td>√</td>
</tr>
<tr>
<td>P1004 (up to 480µm)</td>
<td>√</td>
</tr>
<tr>
<td>Sheet</td>
<td><img src="image" alt="mirel" /> <img src="image" alt="mirel" /> <img src="image" alt="vinicotte" /> <img src="image" alt="mirel" /> <img src="image" alt="vinicotte" /> <img src="image" alt="mirel" /></td>
</tr>
<tr>
<td>P4001</td>
<td></td>
</tr>
<tr>
<td>PHA Base Resins</td>
<td><img src="image" alt="mirel" /> <img src="image" alt="mirel" /> <img src="image" alt="vinicotte" /> <img src="image" alt="mirel" /> <img src="image" alt="vinicotte" /> <img src="image" alt="mirel" /></td>
</tr>
<tr>
<td>M2100</td>
<td>√</td>
</tr>
<tr>
<td>M2200</td>
<td>√</td>
</tr>
<tr>
<td>M4100</td>
<td>√</td>
</tr>
</tbody>
</table>
Anaerobic Digestion

- Mirel is rapidly consumed in both high (thermophilic) and low (mesophilic) temperature digesters
- Mirel is rapidly consumed in high and low solids digesters
- Customers have found Mirel accelerates the digestion of food waste
  - Throughput of anaerobic digesters is increased
<table>
<thead>
<tr>
<th>Processing</th>
<th>Brand</th>
<th>Grade</th>
<th>Description</th>
<th>Calculated bio-content</th>
<th>Biodegradable in ambient environment</th>
<th>Compostable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection molding</td>
<td>Mirel®</td>
<td>P1003</td>
<td>General purpose, higher modulus</td>
<td>91 %</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>Mirel®</td>
<td>P1004</td>
<td>General purpose, higher toughness</td>
<td>89 %</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>Mirel®</td>
<td>P1008</td>
<td>Higher modulus with starch content</td>
<td></td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Sheet extrusion</td>
<td>Mirel®</td>
<td>P4001</td>
<td>High melt strength</td>
<td>85 %</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Sheet extrusion &amp; thermoforming</td>
<td>Mirel®</td>
<td>P3001</td>
<td>High melt strength, suitable for thermoforming</td>
<td></td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Blow and cast film</td>
<td>Mirel®</td>
<td>P5001</td>
<td>High bio-content and many end of life options, heat sealable</td>
<td>77 %</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>Mvera®</td>
<td>B5002</td>
<td>Compostable film blend, excellent melt strength and easy processing, heat sealable</td>
<td>29 %</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>Mirel®</td>
<td>A5004</td>
<td>Agricultural film applications, good melt and draw down stability</td>
<td>49 %</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Base grades for compounding</td>
<td>n. a.</td>
<td>M4100</td>
<td>Base material for film grades</td>
<td>85 %</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>n. a.</td>
<td>M2100</td>
<td>Base material for high modulus grades</td>
<td>95 %</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>n. a.</td>
<td>M2200</td>
<td>Base material for high toughness grades</td>
<td>91 %</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>
Mirel P5001

- Cast and blown film applications
  - Biogas plant collection bags (AD degradable)
  - Marine degradable bags
  - High barrier property films
- Can be processed on conventional equipment and infrastructure
- Fair melt strength
  - Good drawdown stability for blown film processing at reduced processing speed
- Heat sealable
- Shelf stable
- Good Printability
  - Inherently high dyne level
Mvera B5002

- Cast and blown film applications
  - Compost bags for industrial and home use
  - Retail carrier bags
  - Hygiene bags
- Can be processed on conventional equipment and infrastructure
- Excellent melt strength
  - Excellent drawdown stability for blown film processing
- Heat sealable
- Excellent tensile properties
  - Suitable puncture toughness and tear resistance
  - Durable and versatile similar to petro based resins
- Good Printability
  - Inherently high dyne level
Aging of Mvera B5002 (~1 year)

Shelf Life Study of B5002 Blown Film
films tested @ various times post-production

Post-Fabrication Time (days)
0 50 100 150 200 250 300 350

Film Property (g/mil)
100
120
140
160
180
200
220
240

MD Tear
Dart Impact
Application Case Studies
Kitchen Waste Bag

**Material:**
Mirel™ P5001

**Functionality:**
Collection of kitchen waste.

**Advantages:**
- Nice silky touch
- Printable
- Mechanical properties similar to polyolefins
- Kitchen waste can be home composted together with the bag
- Material is sugar and not petro-based

**Partners:**
Various
Marine and AD degradable bags

**Material:**
Mirel™ P5001

**Functionality:**
Replaces traditional bags with marine degradable and anaerobic digestable (AD) film

**Advantages:**
- Nice silky touch
- Printable
- Mechanical properties similar to polyolefins
- No harm to environment when material is erroneously disposed into nature (e.g. in the Ocean)
- Material produces biogas in AD facilities
- High biocontent - Material is sugar and not petro-based

**Partner:**
Cortec, USA and Croatia
Dog Waste Bag

**Material:**
Mirel™ P5001

**Functionality:**
Replaces traditional plastics with home and soil compostable film

**Advantages:**
- Nice silky touch
- Printable
- Mechanical properties similar to polyolefins
- No harm to environment when material is erroneously disposed into nature (e.g. in the ocean or woods)
- Material and dog waste can be home composted
- High biocontent - Material is sugar and not petro based
Compostable Shopping Bags

Material:
Mvera™ B5002

Functionality:
Replaces traditional shopping bags with a compostable film

Advantages:
- Nice silky touch
- Printable
- Mechanical properties similar to polyolefins
- Bag is industrial compostable – Vincotte certified up to 288 µm
- Material is partly biobased

Partner:
Andolfi, Italy

www.andolfi.it
Pulldown bags

**Material:**
Mvera™ B5002

**Functionality:**
Replaces traditional pull down bags (e.g. for fruits, drugs, or cosmetics) with compostable pull down bags

**Advantages:**
- Nice silky touch
- Printable
- Mechanical properties similar to polyolefins
- Bag is industrial compostable – Vincotte certified up to 288 µm
- Material is partly biobased

**Partner:**
Andolfi, Italy

www.andolfi.it
Material:  
Mirel™ P4001

Functionality:  
Replaces plastic plant pot with biodegradable sheet to allow pot to be place directly in the soil

Advantages:  
- Printable – colorful! Logos, technical information and barcode can be printed directly on the product  
- No need to separate and dispose of plant pot before planting. Neater planting with less waste.  
- High biocontent of material

The Greener Package award for nonfood primary packaging was awarded in 2010 to the SoilWrap® plantable container made with Mirel™ biopolymers

Partner:  
Ball, USA

www.BallHort.com
Tulip Bulb Covers

Material:
Mirel™ P1004

Functionality:
Biodegradable packaging for tulip bulbs

Advantages:
- Nice ‘silky’ touch and high surface quality
- High mechanical strength similar to traditional polyolefins
- Various end of life option (composting, Anaerobic Digestion or Home composting)
- No harm to enviroment when material is erroneously disposed of in nature
- Materials Vincotte certified: Compostable to 480 µm, Biodegradable in soil and water
- High biocontent of material

Partner:
Imperial Ventures, The Netherlands  www.abulbc.nl/main
Summary

- Metabolix is a leader in the development of PHA biopolymer alternatives to petroleum-based plastics
- PHA is a versatile, high performance material with a unique biodegradability profile
- Broad set of potential applications; focus on film grades and bag applications