"Sustainable approaches to modern packaging materials - Carbon Footprint Minimisation"

Professor Edward Kosior
Managing Director, Nextek Limited
Nextek Limited – Creating Sustainable Solutions in Polymers and Recycling

Background

Professor/Director RMIT Polymer Tech. Centre
R&D Manager Visy Industries.
Establishment of mixed bottle plant to Visy USFDA rPET process
Revision of Sydney Coca Cola Plant – Phoenix process
Market development bottle, fibre, sheet and moulding applications

RECENT UK Projects

Development of PET recycling plant for Closed Loop  London
Development of a new FDA Food Grade PET Recycling Process
Demonstration of Viability of rPET in Retail Packaging: CLL,  M&S and Boots
Beverage Packaging Waste Reduction: Light weighting PET bottles, Esterform
Using Post-Consumer Tyres in a Range of New Applications: Pipe Sealing System
Development of Light Weight Compostable Packaging- Sainsburys
Demonstration trial of Recycled HDPE into Milk Bottles- WRAP
Summary

• Use of polymers in the building industry
• Recycling of Plastics
• Opportunities and cases studies of polymer recycling, rPET, rHDPE, PVC
• Sustainable biopolymers and bioplastics
• Research and development directions in sustainable plastics and Biopolymers
• Investment in new plant and capacity
• Future Directions
Sustainaball Polymers!

Sustainaball® FACT SHEET

More than 10 million tennis balls are imported into Australia each year - this equates to 670km of tennis balls...

Sustainaball® - a community project exploring the reuse and recycling of tennis balls and promoting a sustainable future.

With State government support through the Sustainability Fund, Sustainaball® initiatives have developed from concept to implementation.

Sustainaball® aims to:

[1] Prolong the use of tennis balls within the local community.
Selected venues in metropolitan Melbourne and regional Victoria have been installed with ball collection bins. Community members are encouraged to utilise these

Closing the loop for Sustainaball®

Vision
To reduce the number of tennis balls ending up in our parks, waterways and maximise resource use by closing the loop.

How?
Reused tennis balls collected in the ball collection bins at local community groups will be incorporated into recycled rubber products by Repeat Rubber Pty Ltd.
This includes products such as:

- Gymnasium flooring
- Acoustic underlay
- Commercial grade sports and play surface coatings
- Moulded products
**Sustainable Materials: Polymers and Products**

- **Embodied Energy**
  - Embodied energy is approx 50% of total energy cost for most plastics

- **Recycled Content**
  - 1 tonne of rPET saves 1.5 tonnes of CO₂

- **Recyclable**
  - Thermoplastics can all theoretically be recycled

- **Long Life Times/ Degradable**
  - Polymers are inherently stable or stabilised to last for 100+ years

- **Sustainable Sources**
  - Polymers are usually derived from fossil fuel sources
  - New Polymers are being made from renewable crops
Commodity plastics used in packaging in the UK 2006

- LDPE/LLDPE: 39%
- HDPE: 13%
- LDPE: 39%
- PET: 15%
- OPP: 5%
- PP: 12%
- PVC: 6%
- Un-specified Polyolefins (PO): 5%

Commodity plastics used in packaging in the UK 2006
The end-uses of plastics used in packaging in the UK 2006

- Bottles: 23%
- Film: 20%
- Film - bags: 17%
- Semi-rigid sheet: 5%
- Thermoformed packs: 8%
- Injection mouldeds, crates etc: 3%
- Others: 20%
Price of polymers as a function of volume of sales

Source: Biomer - Urs J. Haenggi
Historical price of oil 1860 – 2006,
A stimulus for change!

Commercial plastics are made from oil and gas
(China has just purchased rights to SA Lurgi process that uses coal as the raw material)
### Lifetimes of plastics e.g. PVC

<table>
<thead>
<tr>
<th>Application</th>
<th>Production Start-Up (Europe)</th>
<th>Average Lifetime (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe and fittings</td>
<td>1950</td>
<td>46</td>
</tr>
<tr>
<td>Window profiles</td>
<td>1965</td>
<td>40</td>
</tr>
<tr>
<td>Cables</td>
<td>1950</td>
<td>30</td>
</tr>
<tr>
<td>Flooring</td>
<td>1950</td>
<td>15</td>
</tr>
<tr>
<td>Rigid Films (Packaging)</td>
<td>1945</td>
<td>1</td>
</tr>
<tr>
<td>Bottles</td>
<td>1960</td>
<td>1</td>
</tr>
</tbody>
</table>

Source: Helmuth Leitner, Solvay, Belgium (2002)
• UK is the highest consumer of convenience packaging per capita in the world (£7 billion/year)

• Plastics account for > 50% of retail packaging

• UK has an unexploited resource of over 300,000 tpa of PET and 120,000 tpa of HDPE bottles currently going to landfill

• In two years time more than 70,000 tpa of UK PET and 27,000 tpa of HDPE will be required to be recycled

• UK plastics bottle recycling currently stands at 67,000 tpa - 13% compared with > 50% in some European countries

• The National objective is 100,000 tonnes of plastic by 2008 – (22.5% recycling)

• 6 out of 10 Londoners now have a recycling collection from home
What is in UK Plastic Post consumer Waste?

• The total stream is 1.5 million tonnes

• The potentially recoverable plastics packaging in the household waste stream is about 1.2 million tonnes pa;
• Of this total
  • 615,000 tonnes is film plastic packaging
  • 385,000 tonnes are plastic bottles, and
  • 293,000 tonnes is other plastic packaging

• PET and HDPE bottles represent a obvious target for recycling
• Food Grade PET and HDPE represent the highest commercial value products
• Collection of bottles is now growing rapidly
Kerbside vs Bring collection of recyclables

Figure 4: Geographical spread of plastic bottle recycling schemes across the UK by waste collection authority

This map indicates whether a plastic bottle collection scheme operates within, but not necessarily throughout, a local authority area.
Closed Loop vs Cascade Hierarchy for Recycling

Cascade Hierarchy for Recycling
- Primary application (food package)
- Secondary application (building product)
- Energy recovery (incineration)

• Closed Loop Recycling
  - Primary Application to Primary Application
  - Food Package to Food package

• Main Source for Recycled Polymers
  - Short term applications- Packaging
  - Long term applications- Not yet at end of life- limited to waste minimisation
Environmental Case for Recycling
Plastic Bottle Recycling - The Environmental Case

- WRAP commissioned Technical University of Denmark (IPU) and the Danish Topic Centre on Waste
- Reviewed all recycling LCAs that have used ISO methodologies
  - Plastics
  - Paper/cardboard
  - Aluminium
  - Steel
  - Glass
  - Wood
  - Aggregates
## LCA Selection

<table>
<thead>
<tr>
<th>Material</th>
<th>Number of studies evaluated</th>
<th>Number of studies used</th>
<th>Number of scenarios identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>19</td>
<td>11</td>
<td>25</td>
</tr>
<tr>
<td>Wood</td>
<td>29</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Paper and cardboard</td>
<td>108</td>
<td>9</td>
<td>63</td>
</tr>
<tr>
<td>Plastics</td>
<td>42</td>
<td>10</td>
<td>60</td>
</tr>
<tr>
<td>Aluminium</td>
<td>19</td>
<td>11</td>
<td>20</td>
</tr>
<tr>
<td>Steel</td>
<td>31</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>Aggregates</td>
<td>24</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>
Recycling vs Landfill

CO₂-eq. saving from recycling

CO₂-eq. saving from landfill

Saved emission of greenhouse gases in tonne of CO₂-eq. / tonne plastics
Recycling vs Incineration

Plastic Recycling Vs. Incineration

Saved emission of greenhouse gases in tonne of CO₂-eq. / tonne plastics

The LCA covers the entire life cycle. Material substitution ratio recovered: virgin = 1 : 1

The LCA covers the entire life cycle. Cleaning/washing of product with medium to high COD and/or hot water

The LCA covers the entire life cycle. Material substitution ratio recovered: virgin = 1 : 0.5
Recycling 1 tonne of Plastic bottles saves:

1.5 tonnes of CO$_2$

(vs landfill or incineration)
Headline Outputs …

- >225 million packs produced (1600t of rPET)
- No loss on cycle times, added weights etc
- Processing and energy benefits (CCE)
- Cost competitive
- Positive consumer acceptance
- Positive sales
Stimulation Demand rPET
Recycling to Food Contact Quality is now possible. Opportunity to create the highest value for recycling plastics.

- Brand owners are specifying recycled content
- Labels announce environmental features
All food contact materials:

Manufactured according to good manufacturing practice
Not allow constituents to migrate into food in quantities:
- harmful to human health
- affect nature/quality of the food -(including taste and smell)

Current regulations


The Plastic Materials and Articles in Contact with Food (England) Regulations 2006.
- Overall migration limit of 60 ppm into food
- Specific Migration limits for individual substances
- Compliance declarations
- Migration test methods
US FDA regulations

Threshold of Regulation- USA

- Plastics for food contact are always evaluated for any migration that might occur when in contact with food material.
- migrating substances are considered to be food additives.
- “Threshold of Regulation” -a level below which the probable exposure to a potentially toxic substance is a negligible risk (defined as 0.5ppb in daily diet)

US FDA Validation of Recycling Processes

- Any recycling process must demonstrate its ability to remove potential contaminants due to consumer misuse.
- A series of representative chemicals or their surrogates are used to spike PET flake in a “Challenge Test”.
- 100% of flake is contaminated for 2 weeks at 40 deg C. (Flake absorb up to 10 times more contaminants than bottles)
- Mathematical migration modeling is now accepted instead of some testing and approvals.
USFDA “Challenge Test” for Recycling Processes

• “Challenge Test” procedure validation as being capable of removing severe contamination from bottles to below the “level of regulation”

• Provides assurance that much lower levels of contamination in collected bottles will be removed to negligible risk levels.

• From February 1990 to July 2005, 69 “letters of non-objection” have been issued 17 chemical processes and 52 physical recycling processes for rPET

• Chemical recycling no longer requires FDA accreditation.
## Chemicals and Surrogates

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Surrogate</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloroform</td>
<td>Trichloroethane</td>
<td>Polar, Volatile</td>
</tr>
<tr>
<td>Diazinon</td>
<td>Benzophenone</td>
<td>Polar, Non-volatile</td>
</tr>
<tr>
<td>Lindane</td>
<td>Phenyldecanine</td>
<td>Non-polar, Non-Volatile</td>
</tr>
<tr>
<td>Gasoline</td>
<td>Toluene</td>
<td>Non-polar, Volatile</td>
</tr>
<tr>
<td>Disodium Arsenate</td>
<td>Copper Octoate</td>
<td>Organo metallic</td>
</tr>
</tbody>
</table>
Safety factors in USFDA Protocol

Threshold of regulation - 1000 to 500,000
Use of 100% contamination in test - 10,000
Over concentration of surrogates - 10
Consumption factor > 10
Food distribution factor (% recycle) > 2

Total Safety Factors

\[
1000 \times 10,000 \times 10 \times 10 \times 2 = 2 \times 10^9
\]

ie > 2 billion times safety factor
Decontamination results (new WRAP rPET process)

<table>
<thead>
<tr>
<th>Surrogate Chemical</th>
<th>Flake Initial ppm</th>
<th>Flake After wash ppm</th>
<th>Flake After High Temp Decontamination ppm</th>
<th>Limiting levels based on migration into oil ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloroform</td>
<td>592±77</td>
<td>300±24</td>
<td>&lt;0.1</td>
<td>15</td>
</tr>
<tr>
<td>Toluene</td>
<td>736±163</td>
<td>237±32</td>
<td>0.2±0.01</td>
<td>16.6</td>
</tr>
<tr>
<td>Chlorobenzene</td>
<td>649±83</td>
<td>225±26</td>
<td>0.4±0.03</td>
<td>16.7</td>
</tr>
<tr>
<td>Phenylcyclohexane</td>
<td>795±186</td>
<td>507±104</td>
<td>0.6±0.45</td>
<td>21</td>
</tr>
<tr>
<td>Benzophenone</td>
<td>694±180</td>
<td>419±88</td>
<td>1.2±0.99</td>
<td>23.4</td>
</tr>
</tbody>
</table>
Decontamination results

Rt = 1.8 min, Acetaldehyde
Rt = 2.5 min, 2-methyl-1,3-dioxolane
Rt = 2.9 min, ethylene glycol

Input Flake

Washed Flake

Decontaminated Flake

limonene (Rt = 8.1 min)
Conversion to bottles

100% Challenge test pellets
30% recycled content
Conversion to sheet and formed products

Virgin PET  50% rPET
Chemical or Feedstock Recycling

Chemical Recycling
Breakdown of PET into Basic building blocks, purifying and re-polymerising back to Virgin PET

3 key Chemical methods

Methanolysis
Glycolysis
Hydrolysis
Chemical or Feedstock Recycling

Methanolysis

- Depolymerised to produce dimethyl terephthalate (DMT) and ethylene glycol (EG) at around 200ºC.
- The DMT is purified to produce new PET.

Glycolysis

- PET depolymerised to give bishydroxyethylterephthalate (BHET) and purified by melt filtration and with carbon to remove colour and chemical impurities.
- Recent recipients of FDA letters of non-object include:

Hydrolysis

- PET hydrolysed by treatment with water, acids or caustic soda to give terephthalic acid (TA) and ethylene glycol (EG), which may be repolymerised following purification.
- PET hydrolysis is less well commercially established than glycolysis or methanolysis.
- RecoPET / Technochim Engineering in France has a caustic hydrolysis process.
Multi-Layer processing

Requires a virgin layer in the final application in contact with food.
At least 25 micron layer for $T \leq$ room temp
At least 50 micron layers for $T \geq$ room temp

PET preforms/Bottles require tooling with Co-injection capability (Owens Illinois, Hofstetter, Kortec)

Sheet and thermoformed products require 3 layer tooling and sufficiently thick virgin layer to ensure that at least 25 microns remains at the thinnest section.

38% rPET in multilayer

| 10/80/10 Virgin/rPET/Virgin | 30/40/30 Virgin/rPET/Virgin |
UK PET into Food Grade
Initial Steps in recycling PET

All processes will require some common preparation prior to the actual recycling step:

• 1. Debaling of the compressed bottles.
• 2. Sorting of the bottles by people or auto-sorting (NIR) or both
• 3A. Pre-cleaning of the bottles or
• 3B. Shredding of the bottles followed by “Dry Cleaning”
• 4. Grinding to 12 mm flake
• 5. Hot washing of the flake
• 6. Removal of labels and caps - usually by floatation and air elutriation
• 7. De-dusting to remove PET fines as well as fine contaminants.
• 8. Sorting of flake to remove coloured and non PET contaminants (Visible and laser systems)
Impurities in PET bales
Contaminants- What's in a bale

<table>
<thead>
<tr>
<th></th>
<th>Dry Waste</th>
<th>Dry Level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input</strong></td>
<td>8,484</td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>509</td>
<td>6.00%</td>
</tr>
<tr>
<td>Iron wires</td>
<td>127</td>
<td>1.50%</td>
</tr>
<tr>
<td>Labels</td>
<td>681</td>
<td>8.00%</td>
</tr>
<tr>
<td>Manual sorting</td>
<td>1,054</td>
<td>12.40%</td>
</tr>
<tr>
<td>Metal separator</td>
<td>93</td>
<td>1.10%</td>
</tr>
<tr>
<td>Dust</td>
<td>213</td>
<td>2.50%</td>
</tr>
<tr>
<td>Coloured particles</td>
<td>57</td>
<td>0.70%</td>
</tr>
<tr>
<td>Caps</td>
<td>266</td>
<td>3.10%</td>
</tr>
<tr>
<td>Waste in waste water</td>
<td>92</td>
<td>1.10%</td>
</tr>
<tr>
<td><strong>Total waste</strong></td>
<td></td>
<td>36.40%</td>
</tr>
<tr>
<td><strong>PET flakes</strong></td>
<td>5,392</td>
<td>63.60%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contamination Level</th>
<th>Contamination</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET bottles Blue bottles</td>
<td>52.40%</td>
</tr>
<tr>
<td>green bottles</td>
<td>7.20%</td>
</tr>
<tr>
<td>Orange bottles</td>
<td>3.80%</td>
</tr>
<tr>
<td>Yellow bottles</td>
<td>1.00%</td>
</tr>
<tr>
<td>Black bottles</td>
<td>0.50%</td>
</tr>
<tr>
<td>Purple bottles</td>
<td>0.40%</td>
</tr>
<tr>
<td>Others Energy drinks</td>
<td>13.70%</td>
</tr>
<tr>
<td>Non food</td>
<td>9.30%</td>
</tr>
<tr>
<td>PVC</td>
<td>8.10%</td>
</tr>
<tr>
<td>HDPE</td>
<td>1.80%</td>
</tr>
<tr>
<td>Cardboard</td>
<td>0.50%</td>
</tr>
<tr>
<td>Aluminium foil</td>
<td>0.30%</td>
</tr>
<tr>
<td>Tin cover</td>
<td>0.30%</td>
</tr>
<tr>
<td>Traces, boxes</td>
<td>0.40%</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>0.20%</td>
</tr>
</tbody>
</table>
Sorting Bottles and Flakes with Visible and Near Infra Red (NIR)

**Sorters**
- NRT
- Mikrosort
- MSS
- Rofin
- RTT
- S+S
- Satake
- Titech
- Unisensor

**Diagram:**
- Reflection
  - Light source
  - Receiver
  - Object
- Transmission
  - Receiver
  - Object
  - Light source
RTT Uni-sort  NIR– PX Technology

RTT UniSort PX
1 Unit = 3 Fractions

Sensor
Catcher-Hood

Input feeding

Speedconveyor

Conveyor

dual nozzle ejection array

Flowpath
Sorted Fraction e.g.: HDPE
Sorted Fraction e.g.: PET

UNISORT® PX
Triple Sorting Modul
New Flexibility in operation - Sectioned sorters

**RTT UniSort** PX – Section Kombination

**UNISORT® PX**
Ein Gerät drei Fraktionen

**UNISORT® Section 3**
Ein Sensor drei unterschiedliche Sortiersektoren

**PX – Section 3 Kombination** ersetzt 5 Standard Sortiermodule

durch RTT geschützt beim deutschen Patentamt Nr.: DBGM 203 10 406.4
Layout and efficiency of Bottle Sorting
Brantner Austria

Firma Brantner, Österreich, IBS Juni 2004
1. Separation of flakes into a planar stream using visible of spectral data from source reflected or transmitted through light, NIR and laser are in use for sorting analysis of data

2. Operation of ejectors in synchronisation with flake velocity

3. Cling of reject stream to increase recovery rate.
Flake detection for separation

Measurement Resolution within one Channel Section

The following example shows the measurement resolution within one chute:

29 relevant spectra for 6 flakes

>= 1 spectra per flake

In total: 720,000 spectra / second
## Sorting of Problem Materials

### Sorted material / Status Quo

<table>
<thead>
<tr>
<th>Materials</th>
<th>Plastics</th>
<th>PET additives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td>PET</td>
<td>Nylon Multilayer e.g. MXD6</td>
</tr>
<tr>
<td>Silicone</td>
<td>PEN</td>
<td>O₂-Blocker</td>
</tr>
<tr>
<td>Textile Fibers</td>
<td>PVC</td>
<td>prevalent PET colors, also TiO₂-Whitener</td>
</tr>
<tr>
<td>Rubber Labels</td>
<td>PE</td>
<td></td>
</tr>
<tr>
<td>Paper</td>
<td>PP</td>
<td>contaminated flakes</td>
</tr>
<tr>
<td>Glue</td>
<td>PC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PLA</td>
<td></td>
</tr>
</tbody>
</table>
Flake sorting efficiency

POWERSORT Detection Levels

Detection rate > 99%
Detection rate > 95%
Detection rate > 85%
Superclean or Physical Recycling

Main Processes

- involve the removal of volatile contaminants and delivering rPET with IV of 0.75-0.82 dl g⁻¹.

Supercycle™ PET (Amcor)*
Bühler Process (Amcor)*
United Resource Recovery Corporation (URRC)*
Phoenix (PTI)*
Vacurema (Erema Plastic Recycling Systems)
Recostar IV Plus (Starlinger)
Ecoclear (Wellman)
Stehning (OHL)
RPET mechanical recycling processes

INFEED

DEBALE

SORT BOTTLES

METAL REMOVAL

GRIND

DRY CLEAN

HOT WASH

SINK-FLOAT in water

DRY/AIR CLASSIFICATION

METAL REMOVAL

SORT FLAKE

DECONTAMINATION

SORT FLAKE

EXTRUDE TO PELLET

END USE CUSTOMERS
Vacurema (Erema)

The Erema TE-VSV (VacuRema) process converts clean dry bottle flake to crystallised food grade pellets and can also produce a melt for direct extrusion to a finished product.

The VacuRema system has approval from Pepsi USA and in Germany, Switzerland and Austria, with food contact approval applied for in Canada, Hungary and Brazil.

Newer versions of the VacuRema use 3 vacuum reactors for further control over the IV.

The VacuRema process can increase viscosity up to virgin material levels e.g. typically to 0.77 to 0.84 dlg-1.
EREMA Multi KT Vacurema System

Parallel batch operation crystallisation-dryer system "Multi-KT System"

Continuous operation VACUREMA extrusion system

Input material
Vacuum slider
KT 1
Vacuum pump
Crystallisation dryer
KT 2
Vacuum slider

Vacuum lock
Extruder
28 µm / 600mesh melt filter
Pelletising Pellets
The key process stages are: sorting, hot washing, decontamination, filtration, granulation, drying, crystallisation and solid state polycondensation. The technology involves the Bühler Ring Extruder and continuous Solid State Polycondensation (SSP) processes. The first Bühler line was installed by Amcor in Beaune, France in 2001. The plant has an annual output capacity of 20,000 tonnes per year.
United Resource Recovery Corporation (URRC)

PET bottles which are separated out and ground into flakes.

PET flakes are separated from labels, closures, and foreign matter using conventional, dry and wet-operation separating techniques as well as hot washing technology.

In the second stage of the process, the surface of the flakes are coated with caustic compounds. A rotary tubular kiln is heated to 200 °C with residence time of 5 hrs to decontaminate any residual substances and odours.

In the third stage, the cleaned PET is sieved and rinsed free of the salt formed and coloured impurities are removed with colour sorting.

The process can cope with highly contaminated PET as well as making a final product in flake form that can be used directly or extruded before use. The final IV is in the range 0.76 to 0.78.

Plants are currently in use in Europe in Switzerland (Fraunfeld), and Germany, (Cleanaway, in Rostock), and in Mexico.
Level of substitution and Colour

- PET progressively changes to a yellow green colour as it is recycled.
- Too high temperatures during decontamination and extrusion can make it worse.
- Recycling at high substitution levels can mean higher initial colour and faster change in properties after recycling.
- For critical colour and strength applications e.g. CSD, 30% is a high level.
- For less critical applications such as thin sheet e.g. <400 um, 50% is possible.
- Running at 100% recycling rate will quickly cause a change in colour and melt behaviour.

<table>
<thead>
<tr>
<th>Number of cycles</th>
<th>Proportion of original material present after a given number of cycles</th>
<th>% Recycled rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
<td>20%</td>
</tr>
<tr>
<td>1</td>
<td>10.00%</td>
<td>20.00%</td>
</tr>
<tr>
<td>2</td>
<td>1.00%</td>
<td>4.00%</td>
</tr>
<tr>
<td>3</td>
<td>0.10%</td>
<td>0.80%</td>
</tr>
<tr>
<td>4</td>
<td>0.01%</td>
<td>0.16%</td>
</tr>
<tr>
<td>5</td>
<td>0.00%</td>
<td>0.03%</td>
</tr>
<tr>
<td>6</td>
<td>0.00%</td>
<td>0.01%</td>
</tr>
<tr>
<td>7</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>8</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>9</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>10</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>
The Closed Loop London Recycling Plant

- located in East London
- the first facility in the UK to take in post consumer waste and convert it to food grade material
- divert 35,000 tonnes p.a of plastic waste from landfill to valued applications, processing 2 tonnes/hour
Recycled HDPE into Milk Bottles
Recycling of HDPE into Food Contact

Fraunhofer IVV (Process Engineering and Packaging) was commissioned by WRAP to develop a process.

Fraunhofer IVV successfully developed a process which complies with EU/UK food contact regulations.

Submission for food contact approval to US FDA – a decision is expected shortly.

Current project is the 1st large scale trial using typical UK material feedstock.

This large scale trial utilised current industrial scale processes.
HDPE Recycling Process - Key Steps

Consistent quality feedstock supply (Recoup)
Bottle Sorting into Milk bottles (RTT)
Bottle Granulation into Flakes
Correct Washing Chemistry & Process (Sorema, B+B)
Flake Sorting Technology (S+S, Mogensen)
Super-clean Decontamination Technology (EREMA)
Extrusion and Filtration into Pellets
Food Contact Suitability & Migration & Sensory Testing (PIRA & Fraunhofer IVV, RSSL, CCFRA)
Blow Moulding of Bottles with 30% rHDPE (Nampak)
Milk Filling of Bottles (Dairy Crest)
Distribution of Milk Bottles to consumers (Marks and Spencer)
Recycling steps

1. Sourcing HDPE bottles from UK MRFs

2. Pre-processing the HDPE bottles.
   - Bales will be pre-processed by sorting into Natural HDPE milk bottles
   - Grinding of bottles to (10 mm) flake

3. Decontamination of HDPE flake, Stage 1
   - The flake is hot washed (>90 deg C & 12 min) and labels removed

4. Colour sorting of the ground flake
   - into coloured and natural (>99.5%) fractions

5. Final Decontamination HDPE Flake, Stage 2
   - Double Vacuum high temperature processing and Extrusion.
   - Step 1 90 deg C, 3-5 mbar 30 min, Step 2 120 deg C, 1-2 mbar 45 min
   - Flake extruded (220 deg C) with vacuum degassing and melt filtered to make it comparable with virgin resins.

6. Conversion to products and performance evaluation.
   - Decontaminated HDPE resins will be converted to bottle products for evaluation of their performance as final products for food contact applications.
HDPE Feedstock

UK feedstock stream relatively immature

Difficult to obtained milk bottles only.

Coloured and clear household cleaning HDPE bottles

Levels of contamination can also vary between collection schemes and MRF's

The quality of the final resin is directly influenced by the composition of feedstock
RTT Uni-sort NIR– PX Technology

Sorters
NRT
Mikrosort
MSS
Rofin
RTT
S+S
Satake
Titech
Unisensor

Sensor
Input feeding
Speedconveyor
Catcher-Hood
Conveyor
dual nozzle ejection array
Flowpath Sorted Fraction e.g.: HDPE
Sorted Fraction e.g.: PET

UNISORT® PX
Triple Sorting Modul
LESSONS LEARNT & EMERGING RECOMMENDATIONS:
Ideally need to have automated bottle sorting to remove non-PE bottles and clear/coloured household cleaning HDPE bottles.

Need intensive hot wash conditions for label and glue removal.
Label and Ink issues

Certain labels have strong glues - difficult to remove;
Inks in some labels can leach out and coat flakes.
Flake Sorting

Sorting of flake resulted in natural-HDPE material purity > 99.4%

Coloured HDPE input into VACUREMA system 0.2 – 0.6%.

Removal of coloured HDPE flakes from bottles and caps

Important to remove multi-layer bottle flake with black mid-layer
Figure 25: Process flow for the EREMA process for super-clean decontamination (two-step process)
Table 19: Initial surrogate concentrations in the contaminated material and cleaning efficiency after each recycling step

<table>
<thead>
<tr>
<th></th>
<th>Toluene</th>
<th>Chlorobenzene</th>
<th>Phenyl cyclohexane</th>
<th>Methyl stearate</th>
<th>Benzophenone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial concentration for washing and super-clean recycling [ppm]</td>
<td>722 ± 142</td>
<td>917 ± 294</td>
<td>852 ± 503</td>
<td>739 ± 566</td>
<td>884 ± 611</td>
</tr>
<tr>
<td>Super-clean process (1-step)</td>
<td>99.2%</td>
<td>99.1%</td>
<td>78.2%</td>
<td>33.7%</td>
<td>11.2%</td>
</tr>
<tr>
<td>Super-clean process (2-step)</td>
<td>99.8%</td>
<td>99.8%</td>
<td>94.5%</td>
<td>75.6%</td>
<td>38.1%</td>
</tr>
<tr>
<td>Washing and super-clean recycling (1-step)</td>
<td>99.7%</td>
<td>99.6%</td>
<td>71.0%</td>
<td>&gt;33.7%</td>
<td>34.5%</td>
</tr>
<tr>
<td>Washing and super-clean recycling (2-step)</td>
<td>99.9%</td>
<td>99.9%</td>
<td>95.0%</td>
<td>&gt;75.6%</td>
<td>54.3%</td>
</tr>
</tbody>
</table>
One step vs Two step Erema

Concentration of surrogate chemicals by Head Space Gas Chromatography
Figure 26: Concentrations in the output material from the EREMA two-step recycling process plotted against time after contamination (analysis of solvent extracts from the HDPE material)
Recycled HDPE milk bottle resin

Colour at 100%

Rheology

<table>
<thead>
<tr>
<th>MFR Tests (g/10min)</th>
<th>Ave. of 1-5</th>
<th>Innoven HD6007S</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFR 2.16 (London Met Uni Tests)</td>
<td>0.58</td>
<td>0.58</td>
</tr>
<tr>
<td>MFR 2.16 (Innovene Lab in Lillo)</td>
<td>0.62</td>
<td>0.60</td>
</tr>
<tr>
<td>MFR 21.6kg (Innovene Lab in Lillo)</td>
<td>46.8</td>
<td>52</td>
</tr>
<tr>
<td>MFR Ratio (21.6/2.16) (Lillo)</td>
<td>76.7</td>
<td>87</td>
</tr>
</tbody>
</table>
## Physical Properties

<table>
<thead>
<tr>
<th>Tensile Test Parameter</th>
<th>Virgin HDPE Innovene Rigidex HD6007S</th>
<th>Recycled HDPE blend of samples 1 to 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yield Stress (MPa)</strong></td>
<td>29.91</td>
<td>30.47</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.084</td>
<td>0.425</td>
</tr>
<tr>
<td><strong>Elongation at yield (%)</strong></td>
<td>12.62</td>
<td>12.63</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.303</td>
<td>0.069</td>
</tr>
<tr>
<td><strong>Stress at Break (MPa)</strong></td>
<td>18.23</td>
<td>20.36</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.595</td>
<td>1.655</td>
</tr>
<tr>
<td><strong>Elongation (%)</strong></td>
<td>35.47</td>
<td>35.06</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>1.620</td>
<td>3.133</td>
</tr>
<tr>
<td><strong>Tensile Modulus (MPa)</strong></td>
<td>332</td>
<td>354</td>
</tr>
</tbody>
</table>

*Data from experimental stress/strain curves

**Figure 2.** Stress/Strain Curves for Virgin HDPE samples

**Figure 3.** Stress/Strain Curves for Recycled HDPE samples
Decontamination removed a wide number of compounds in both virgin resin and the HDPE flake.

Most of the non typical compounds are related to flavour and fragrance compounds such as limonene.

All bottle samples have similar headspace fingerprints.

r HDPE and 100% virgin HDPE milk bottles show no significant differences.

Primary fragrance in flake was limonene – significantly reduced in super-cleaned pellets.

One flake sample showed compounds such as alpha-pinene, camphene, eucalyptol and isobornylacetate.

Milk bottles containing rHDPE showed no significant difference when tested for contaminants and compared to 100% virgin HDPE reference bottles.
Flake → Pellet Decontamination Results

100% Virgin HDPE Pellets →

Material A Flake →

Material A Super-cleaned Pellets →
Bottle Results

100% Virgin HDPE Bottles →

30% Material A rHDPE Bottles →

30% Material B rHDPE Bottles →
Overall Migration tests based on:

EC Directive No. 1935/2004  Current Regulation for Milk = (Simulant is Distilled Water at 5°C)
European Standard Test Method – EN 1186-9 10 days at 20°C, 3% acetic acid / 50% ethanol

EU & UK Legal Limit = 10mg/dm² contact surface or 60mg/kg food simulant

### Fraunhofer IVV

<table>
<thead>
<tr>
<th>Material</th>
<th>Simulant</th>
<th>Migration</th>
<th>Migration Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% Virgin HDPE</td>
<td>3% Acetic Acid</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>30% rHDPE</td>
<td>3% Acetic Acid</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>100% Virgin HDPE</td>
<td>50% ETOH</td>
<td>0.2</td>
<td>10</td>
</tr>
<tr>
<td>30% rHDPE</td>
<td>50% ETOH</td>
<td>0</td>
<td>10</td>
</tr>
</tbody>
</table>

### PIRA

<table>
<thead>
<tr>
<th>Material</th>
<th>Simulant</th>
<th>Migration</th>
<th>Migration Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% r HDPE</td>
<td>50% ETOH</td>
<td>4.2</td>
<td>60</td>
</tr>
<tr>
<td>30% rHDPE</td>
<td>50% ETOH</td>
<td>2.3</td>
<td>60</td>
</tr>
</tbody>
</table>
**Issue:** What is the migration of moderately volatile, unidentified substances?

Test conditions – 50% ethanol for 10 days at 5°C, and 2 days at 20°C, followed by 5 days at 5°C

Virgin HDPE control bottles were tested for comparison.

Test solutions extracted with n-heptane for analysis by GC.

Internal standards were added to the 10 day test solutions, at 16, 10 and 3.2 ppb.

**Results**

No peaks larger than the internal standards were seen in the recycled bottle extracts that were not also present in the control extracts in both sets of migration tests.

**Conclusions**

There is no detectable migration of individual components into 50% ethanol with a LOD equating to 10 ppb, or better.

Migration levels of specific substances into 50% ethanol are below 3.2 ppb

This value is below the US FDA threshold of regulation of 0.5 ppb in the diet, after applying the FDA Consumption Factor of 0.13 for HDPE.

“there is now substantial evidence that the use of recycled HDPE for the packaging of milk is unlikely to endanger human health”. 
**Independent opinion**

Keller & Heckmann reviewed all test data to provide an independent opinion of the safety of this material for an initial production of HDPE milk bottles for marketing and commercial purposes.

**Conclusion**

“Based on the information you have provided, ................. we have no hesitation concluding that the recycled HDPE milk bottles fully comply with the EU Plastics Directive and the general safety requirement under Article 3 of the Framework Regulation and, thus, can be placed and sold in the UK market”.
Machine set-up parameters did not need to be changed.

Successfully blow moulded 4 pint bottles with 30% rHDPE blend.

Feedstock variation can result in variations in odour of the bottles.

No differences in stability and organoleptic tests.
Milk Filling Results

Filling 30% rHDPE containing bottles with different types of milk (skim, semi-skim and full cream) did not show significant colour variation to 100% virgin HDPE bottles.
Test Data

Testing & Validation considerations

Legal
Food Safety - Material
Food Safety - Process

Performance
Processing capability
Physical performance of material
Physical performance of product

Organoleptic
Odour
Colour
Taint

Micro Stability
Test Data

Testing & Validation considerations

Food Safety - Material
✓ Overall migration results
  PIRA & FRAUNHOFER

Food Safety - Process
✓ Specific migration results
  FRAUNHOFER IVV

Material and Process Review
✓ Keller and Heckmann

Performance - does it work?
Processing capability
✓ Trial machine operated
✓ Large scale trial completed

Physical performance of material and product
✓ Key properties meet specification
  PIRA, Dairy Crest & Nampak
Test Data

**Organoleptic – is there a difference?**

Sensory tests carried out on filled product

- No taste or odour difference detected in milk against virgin material.
- No taints detectable

Reading Scientific Services Ltd
Camden and Chorleywood Food Research Association (CCFRA)

**Micro Stability – is this consistent**

Full range micro testing after filling

- No ‘contamination’ identified

CCFRA
### Costs, Power, Staff

<table>
<thead>
<tr>
<th>Item</th>
<th>Wash plant</th>
<th>Vacurema Line</th>
<th>ANCILLARIES</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capital Cost</strong></td>
<td>£1,053,649</td>
<td>£1,179,323</td>
<td>£780,633</td>
<td>£3,013,605</td>
</tr>
<tr>
<td><strong>Floor Space m²</strong></td>
<td>600</td>
<td>100</td>
<td>150</td>
<td>850</td>
</tr>
<tr>
<td><strong>Water m³/hr</strong></td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td><strong>Power kW</strong></td>
<td>313</td>
<td>475</td>
<td>75</td>
<td>863</td>
</tr>
<tr>
<td><strong>Output kg/hr</strong></td>
<td>1000</td>
<td>1400-1000</td>
<td>NA</td>
<td>1000</td>
</tr>
<tr>
<td><strong>Operators and staff</strong></td>
<td>3×5 + 5 = 20</td>
<td>1</td>
<td>0</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 6. Summary of capital costs and utilities for a stand alone plant.

<table>
<thead>
<tr>
<th>Summary</th>
<th>Wash plant</th>
<th>Vacurema Line</th>
<th>ANCILLARIES</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capital Cost</strong></td>
<td>£1,053,649</td>
<td>£1,179,323</td>
<td>£222,992</td>
<td>£2,455,964</td>
</tr>
<tr>
<td><strong>Floor Space m²</strong></td>
<td>600</td>
<td>100</td>
<td>50</td>
<td>750</td>
</tr>
<tr>
<td><strong>Water m³/hr</strong></td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td><strong>Power kW</strong></td>
<td>313</td>
<td>475</td>
<td>75</td>
<td>863</td>
</tr>
<tr>
<td><strong>Output kg/hr</strong></td>
<td>1000</td>
<td>1400-1000</td>
<td>NA</td>
<td>1000</td>
</tr>
<tr>
<td><strong>Operators and staff</strong></td>
<td>3×5 + 1.65 = 16.65</td>
<td>1</td>
<td>0</td>
<td>16.65</td>
</tr>
</tbody>
</table>

Table 7. Summary of capital costs and utilities for a shared plant.
## Process Costs

<table>
<thead>
<tr>
<th>COSTS</th>
<th>Stand alone £/t Recyclate</th>
<th>Shared Plant £/t Recyclate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input purchase and other costs (1)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDPE bottles as purchased</td>
<td>265</td>
<td>265</td>
</tr>
<tr>
<td>HDPE bottles true cost based on output (1)</td>
<td>359.35</td>
<td>359.35</td>
</tr>
<tr>
<td><strong>Process Costs (2)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>By product costs</td>
<td>-18.78</td>
<td>-18.78</td>
</tr>
<tr>
<td>Personnel</td>
<td>90.65</td>
<td>74.09</td>
</tr>
<tr>
<td>Energy</td>
<td>85.22</td>
<td>85.22</td>
</tr>
<tr>
<td>Water and chemicals</td>
<td>19.69</td>
<td>19.69</td>
</tr>
<tr>
<td>Maintenance</td>
<td>24.62</td>
<td>20.06</td>
</tr>
<tr>
<td>Inspection</td>
<td>15.00</td>
<td>15.00</td>
</tr>
<tr>
<td>Packaging</td>
<td>7.79</td>
<td>7.79</td>
</tr>
<tr>
<td>Overheads &amp; rent</td>
<td>72.03</td>
<td>26.38</td>
</tr>
<tr>
<td><strong>Sub-total Process Costs (2)</strong></td>
<td><strong>296.22</strong></td>
<td><strong>229.46</strong></td>
</tr>
<tr>
<td>Depreciation (3)</td>
<td>55.23</td>
<td>42.12</td>
</tr>
<tr>
<td><strong>Total Costs (1+2+3)</strong></td>
<td><strong>711</strong></td>
<td><strong>631</strong></td>
</tr>
</tbody>
</table>

### Additional Financial Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Stand alone</th>
<th>Shared Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Plant Capital</strong></td>
<td>£3,013,605</td>
<td>£2,455,964</td>
</tr>
<tr>
<td>HDPE output t/yr</td>
<td>6,121</td>
<td>6,121</td>
</tr>
<tr>
<td><strong>Sales (equal to Virgin) £/t</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross sales £/yr</td>
<td>£4,896,681</td>
<td>£4,896,681</td>
</tr>
<tr>
<td><strong>EBIT margin £/yr</strong></td>
<td>£89</td>
<td>£169</td>
</tr>
<tr>
<td>Gross Margin £/yr</td>
<td>£546,010</td>
<td>£1,034,894</td>
</tr>
<tr>
<td><strong>Profit on Sales%</strong></td>
<td>11%</td>
<td>21%</td>
</tr>
<tr>
<td>Simple pay back (years)</td>
<td>5.519</td>
<td>2.373</td>
</tr>
</tbody>
</table>
Effect of HDPE Sales Pricing on Plant Profit (EBIT %) at 25% Incoming Material Loss
(Stand Alone HDPE Plant)

Plant Profit (EBIT %)

Price of pre-sorted HDPE balestock (£/tonne)
Plant EBIT at various bale purity and loss rate

Effect of Incoming Bale Purity (Material Loss Rate) on Plant Profit

Plant Profit (EBIT %)

Incoming Material Loss (%)
Sustainable Materials: Polymers and Products

• **Embodied Energy**
  - Embodied energy is approx 50% of total energy cost for most plastics

• **Recycled Content**
  - 1 tonne of rPET saves 1.5 tonnes of CO₂

• **Recyclable**
  - Thermoplastics can all theoretically be recycled

• **Long Life Times/ Degradable**
  - Polymers are inherently stable or stabilised to last for 100+years

• **Sustainable Sources**
  - Polymers are usually derived from fossil fuel sources
  - New Polymers are being made from renewable crops
Biodegradation of plastics

Only one European Standard currently exists for packaging materials, EN13432. There is no current standard for home composting.

STEPS

1. The material and all the components included are characterised and identified to guarantee absence of negative effects on the final compost: ex. heavy metals.
2. Biodegradability is tested in an aquatic or mature compost environment by measuring the carbon dioxide formed. This provides data for the calculation of the degree of biodegradation.
3. Product is tested for disintegration in fresh compost or mature compost, or in activated vermiculite under optimal conditions.

EN13432 stipulates active aeration of the item in compost at an elevated temperature (58 C +/-2 C) over a period of three months. If after the three month period, the material has disappeared to carbon dioxide and water then the material is said to be biodegraded.

4. Subjecting the material to a maturing stage of 3-6 months, afterwards for eco-toxicity and soil improvement.
Biodegradable Polymers

Bio-based Polymers

Polymers extracted from biomass

- Polysaccharides
  - SOY
  - Gluten casein
  - Starch
    - Potato
    - Corn
    - Wheat
    - Rice
    - Tapioca
  - Cellulose
    - Wood
    - Hemicellulose
    - Chitin/Chitosan
  - Other
    - Lignin
    - Guar Gum
    - Pectin

Proteins

- Polylactic Acid
- PHA

Other

Synthesised from Bio derived monomers

Produced from Micro-organisms

Bacterial compounds

Polymers from non renewable sources

- Polycaprolactone (PCL)
- Co-Polyester Aliphatic PBSA
- Co-Polyester Aromatic PBSA
- Polytrimethylene Terephthalate
Starch Polymers

Starch is a granular material from vegetable origin that is composed of two natural polysaccharides: Amylopectin and Amylose which have different molecular weights and structures.

- Amylopectin being almost linear,
- Amylose has a highly branched structure

Pure starch provides brittle and friable materials.

This can be improved by destructurisation where the granular structure of starch is destroyed by the combined use of shear, temperature and time to provide a homogeneous material.

Plasticisers and Polymers can also toughen the starch based polymers.
Depending on the blends, Starch based polymers may or may not be water soluble.
Starch based Plastics

Breakdown of corn and blending with biopolymer to make plastics films and bags
## Key Starch Producers

<table>
<thead>
<tr>
<th>Producer</th>
<th>Region</th>
<th>Trade name</th>
<th>Capacity (kt p.a) 2006</th>
<th>Price (€/kg) 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avebe</td>
<td>Europe</td>
<td>Paragon</td>
<td>10</td>
<td>1.50-4.5</td>
</tr>
<tr>
<td>Biop Biopolymer Technologies</td>
<td>Europe</td>
<td>Biopar</td>
<td>(17 in 2007, 100 in 2015)</td>
<td>1.50-4.5</td>
</tr>
<tr>
<td>Biotec</td>
<td>Europe</td>
<td>Envar, Bioplast, Bioflex</td>
<td>20&lt;sup&gt;a)&lt;/sup&gt;</td>
<td>1.50-4.5</td>
</tr>
<tr>
<td>Novamont</td>
<td>Europe</td>
<td>Mater-Bi</td>
<td>NA</td>
<td>1.50-4.5</td>
</tr>
<tr>
<td>Plantic</td>
<td>Australia</td>
<td>NA</td>
<td>NA</td>
<td>na</td>
</tr>
<tr>
<td>BioPearls</td>
<td>Europe</td>
<td>Pearls</td>
<td>NA</td>
<td>1.3-4</td>
</tr>
<tr>
<td>National Starch and Chemical</td>
<td>US</td>
<td>EcoFoam</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Stanelco</td>
<td>Europe</td>
<td>Starpol, Bioplast</td>
<td>12</td>
<td>1.4-4.2</td>
</tr>
<tr>
<td>Rodemburg biopolymers</td>
<td>Europe</td>
<td>Solanyl</td>
<td>40</td>
<td>1</td>
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<tr>
<td>Japan Cornstarch</td>
<td>Japan</td>
<td>Cornpol</td>
<td>NA</td>
<td>Na</td>
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<tr>
<td>Nihon Shokukin Kako</td>
<td>Japan</td>
<td>NA</td>
<td>NA</td>
<td>Na</td>
</tr>
<tr>
<td>PaperFoam</td>
<td>Europe</td>
<td>PaperFoam&lt;sup&gt;b)&lt;/sup&gt;</td>
<td>NA</td>
<td>na</td>
</tr>
</tbody>
</table>

<sup>a)</sup> Includes 2007 and 2015 capacity figures. 
<sup>b)</sup> Price range not available.
# Starch polymer properties

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Starch (&gt;85%) co-Polyester</th>
<th>Starch/PCL</th>
<th>Starch/Cellulose Acetate</th>
<th>Starch/Cellulose Acetate</th>
<th>Ester starch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mater-Bi&lt;sup&gt;a)&lt;/sup&gt; NF01U</td>
<td>Mater-Bi&lt;sup&gt;a)&lt;/sup&gt; ZF03U/A</td>
<td>Mater-Bi&lt;sup&gt;a)&lt;/sup&gt; ZF03U/A</td>
<td>Bioplast&lt;sup&gt;b)&lt;/sup&gt; GF105/30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melt flow rate (g/ 10 min)</td>
<td>2–8</td>
<td></td>
<td>5–6</td>
<td>5–6</td>
<td></td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>1.3</td>
<td></td>
<td>1.21</td>
<td>1.21</td>
<td></td>
</tr>
<tr>
<td>Transparency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensile strength at yield (MPa)</td>
<td>25</td>
<td>31</td>
<td>26</td>
<td>44,38</td>
<td>30</td>
</tr>
<tr>
<td>Elongation at yield (%)</td>
<td>600</td>
<td>900</td>
<td>27</td>
<td>400–500</td>
<td>600–900</td>
</tr>
<tr>
<td>Flexural Modulus (MPa)</td>
<td>120</td>
<td>180</td>
<td>1700</td>
<td></td>
<td>10–30</td>
</tr>
<tr>
<td>Thermal Properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDT (°C)</td>
<td></td>
<td></td>
<td></td>
<td>65</td>
<td>105–125</td>
</tr>
<tr>
<td>Vicat softening point (°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melting point (°C)</td>
<td>110</td>
<td>64</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Rodemburg Starch products
Foamed starch trays for meat and fruit

Foamed Starch/polymer trays – Sirap Gema
Plantic® trays in Nestlé Dairy Box
Cellulose is a linear homopolymer of glucose molecules.

Cellulose may be used to make flexible and transparent films.

The best known example is Cellophane, a regenerated cellulose, obtained by extrusion of an alkaline dispersion of xanthate of cellulose in an acid bath.

A film is obtained after treatment with a plasticiser (glycerol) and drying.

Cellophane is not thermoplastic and cannot be thermoformed.

Esters and ethers of cellulose can also be obtained.

Some, like cellulose acetate (CA), propionate (CAP) and butyrate (CAB) are thermoplastic products of commercial importance.

From an environmental point of view, these processes have been criticised because they are energy intensive, and create large amounts of carbon dioxide emissions.
## Cellulose based Polymers - Producers

<table>
<thead>
<tr>
<th>Producer</th>
<th>Region</th>
<th>Trade name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastman</td>
<td>US</td>
<td>Tenite</td>
</tr>
<tr>
<td>Lenzig</td>
<td></td>
<td>Lyocell</td>
</tr>
<tr>
<td>Accordis</td>
<td></td>
<td>Tencell</td>
</tr>
<tr>
<td>Mazzuccheli</td>
<td>EU</td>
<td>Biocetta</td>
</tr>
<tr>
<td>Innovia</td>
<td>EU</td>
<td>Natureflex</td>
</tr>
<tr>
<td>Weyerhauser, US</td>
<td>US</td>
<td>Cellulon</td>
</tr>
<tr>
<td>Ajinomoto, Japan</td>
<td>US</td>
<td>N/a</td>
</tr>
<tr>
<td>Vegemat, France</td>
<td>EU</td>
<td>Vegemat</td>
</tr>
<tr>
<td>Greenidea</td>
<td>Asia</td>
<td></td>
</tr>
<tr>
<td>Ecopack</td>
<td>Asia</td>
<td></td>
</tr>
</tbody>
</table>

Innovia film Flow Wrap
Cellulose Films

NatureFlex™
2nd Generation, High receptivity coating

- E946 - Transparent, ‘easy print’ & semi-permeable to H₂O
- E947M - Metallised high barrier

Currently undergoing customer trials & Independent Compostability testing to ASTM D6400 & EN13432 standards
# Cellulose based Polymers - Properties

<table>
<thead>
<tr>
<th></th>
<th>Vegemat</th>
<th>Biocetta</th>
<th>Biograde</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical properties</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melt flow rate (g/10 min)</td>
<td>2-8</td>
<td></td>
<td>1-5</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>1.45</td>
<td>1.25</td>
<td>0.99</td>
</tr>
<tr>
<td><strong>Mechanical properties</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensile strength at yield (MPa)</td>
<td>22</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Elongation at yield (%)</td>
<td>0.67</td>
<td>62</td>
<td>3.13</td>
</tr>
<tr>
<td>Flexural Modulus (MPa)</td>
<td>3300</td>
<td></td>
<td>6531</td>
</tr>
<tr>
<td><strong>Thermal Properties</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDT (ºC)</td>
<td>77</td>
<td>65</td>
<td>181</td>
</tr>
<tr>
<td>Vicat softening point (ºC)</td>
<td>111</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Plastics from whole corn

Plastics injection moulded from whole grain corn - Vegeplast France
Plastics from Sunflower seed waste from bio-diesel production

Products injection moulded from Sunflower oil cake
Poly Lactic Acid

NO PETROLEUM NEEDED

Refining corn can yield plastic, which can be shaped into medical sutures, plastic cups, candy wrappers and even bedding. A look at how it works:

Corn kernels are soaked and ground. Starch from the endosperm is separated from the gluten and fiber. Enzymes are added, converting the starch into dextrose, a simple sugar.

Bacterial cultures are added to ferment the dextrose into lactic acid. Through further refining, the water is removed from the lactic acid, producing simple molecules called lactides. These molecules bond together into long chains, or polymers.

To the eye, the result is a small pellet that can be spun into fiber to make clothes or bedding, or melted and shaped into products, like those pictured below.

The cups and containers can be composted at large-scale facilities, where raw materials move through the composting process in 45 days, at a temperature of about 140 degrees Fahrenheit and humidity of 95%.

Early tests show that these items can also be recycled with petroleum-based plastics.
Lactic acid is produced by the fermentation of carbohydrate material, usually glucose derived by hydrolysis from starch.

Poly lactic acid is made by a ring opening reaction from the lactide.

Polymerisation of l-lactide produces a semi crystalline polymer with a melting point of 170–180 °C and a glass transition temperature around 60 °C.

PLA does not contain any genetic DNA, however there is concern over the use of GM sourced PLA in Europe.

PLA is often blended with Co Polyesters and/or starch to make less stiff yet biodegradable plastics.

PLA requires temperatures over 70 deg C before biodegradation occurs. It will not decompose in a home composter.
PLA in packaging
INGEO PLA fibre products from corn Toray and Cargill

Products include
- Carpets with better stain resistance (Terratex by Interface)
- Doonas and fibre-fill products
- Disposable wipes
- Fashion clothes, socks (silk like properties and low odour retention)
<table>
<thead>
<tr>
<th>Producer</th>
<th>Trade name</th>
<th>2006 Capacity</th>
<th>2006 Price (€/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomer</td>
<td></td>
<td>0.05</td>
<td>10-12</td>
</tr>
<tr>
<td>Natureworks (Cargill)</td>
<td>Natureworks</td>
<td>140</td>
<td>1.8-2.4</td>
</tr>
<tr>
<td>(Mitsui Lacea in Japan)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dainippon.</td>
<td></td>
<td>N/a</td>
<td>N/a</td>
</tr>
<tr>
<td>Hycaill</td>
<td>Hycaill HM, Hycaill LM</td>
<td>1</td>
<td>1.8-2.9</td>
</tr>
<tr>
<td>Mitsubishi Plastics</td>
<td></td>
<td>N/a</td>
<td>N/a</td>
</tr>
<tr>
<td>FKuR Kunststoff</td>
<td></td>
<td></td>
<td>2.85-3.70 a)</td>
</tr>
<tr>
<td>Toyota</td>
<td>Toyota-Eco-Plastic</td>
<td>50 (2004)</td>
<td>N/a</td>
</tr>
<tr>
<td>Kaneka Corporation</td>
<td></td>
<td>N/a</td>
<td>N/a</td>
</tr>
<tr>
<td>Toyobo</td>
<td></td>
<td>N/a</td>
<td>N/a</td>
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</table>
Comparison of PLA and PET

PLA is more rigid and of a lower density than PET.
This allows packaging and fibres to be made thinner for the same stiffness resulting in Weight Savings of at least 15-20%.

<table>
<thead>
<tr>
<th></th>
<th>PET</th>
<th>PLA</th>
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<tbody>
<tr>
<td>Modulus (MPa)</td>
<td>2400</td>
<td>3500</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>1400</td>
<td>1250</td>
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<tr>
<td>Modulus/density</td>
<td>1.71</td>
<td>2.80</td>
</tr>
<tr>
<td>% increase in stiffness</td>
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<td>38.78</td>
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</table>
## Poly Lactic Acid - Properties

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>NatureWorks PLA</th>
<th>Biomer L9000</th>
<th>Hycaill HM1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melt flow rate (g/10 min)</td>
<td>4.3</td>
<td>3-6</td>
<td></td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>1.25</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>Transparency</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellowness index</td>
<td>20-60</td>
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### Mechanical properties

<table>
<thead>
<tr>
<th></th>
<th>NatureWorks PLA</th>
<th>Biomer L9000</th>
<th>Hycaill HM1</th>
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<tbody>
<tr>
<td>Tensile strength at yield (MPa)</td>
<td>53</td>
<td>70</td>
<td>102</td>
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<tr>
<td>Elongation at yield (%)</td>
<td>10-100</td>
<td>2.4</td>
<td>7</td>
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<tr>
<td>Flexural Modulus (MPa)</td>
<td>350-450</td>
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<td>350</td>
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### Thermal Properties

<table>
<thead>
<tr>
<th></th>
<th>NatureWorks PLA</th>
<th>Biomer L9000</th>
<th>Hycaill HM1</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDT (°C)</td>
<td>40-45,135</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vicat softening point (°C)</td>
<td>-</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Melting point (°C)</td>
<td>55-65</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Microbially synthesised polyhydroxy alkanoates PHA

Metabolix USA

Metabolix has teamed with Archer Daniels Midland (ADM) as a strategic partner to commercialize earth-friendly Natural Plastic. The first commercial plant will be in Clinton, Iowa, and startup is planned for 2008. ADM is one of the largest agribusinesses in the world. Their extensive capability enables commercial availability of Natural Plastic globally. Metabolix is now working with select customers to prototype and develop applications.

Particles of PHA in the micro-organism

Natural Plastic is made from renewable resources like corn sugar and oil which become the feedstock for microorganisms that produce polymer. It is made into pellets that can be turned into products like paper coatings and thermoformed lids. At the end of life, these biodegrade harmlessly and again become the feedstock for plants and microorganisms.
Polyhydroxybutyrate-co-hexanoate (PHBH)
Procter & Gamble and Kaneka have introduced a range of PHBH, under the trade mark of Nodax.
The properties of Nodax are a function of the concentration of the hexanoate, which vary from hard with some flexibility (4%), hard elastic (6%), soft elastic (8%), soft rubbery (18%), allowing to manufacture a range of materials (injected moulded, films, or fibres).
## PHA producers

<table>
<thead>
<tr>
<th>Producer</th>
<th>Region</th>
<th>Trade name</th>
<th>2006 Capacity (kt p.a)</th>
<th>2008 Capacity (kt p.a)</th>
<th>2006 Price (€/kg)</th>
<th>2008 Price (€/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolix &amp; ADM</td>
<td>North America</td>
<td></td>
<td>5</td>
<td>50,000</td>
<td>10-Dec</td>
<td>2.5</td>
</tr>
<tr>
<td>Procter&amp;Gamble/Kaneka</td>
<td>North America</td>
<td>Nodax</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
</tr>
<tr>
<td>Biomer</td>
<td>EU</td>
<td></td>
<td>0.5</td>
<td>0.5</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>PHB Industrial</td>
<td>South America</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomatera, inc</td>
<td>North America</td>
<td></td>
<td>0.05</td>
<td>10</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Mitsubishi Gas Chemical (MGC)</td>
<td>Asia</td>
<td></td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
<td>N/a</td>
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## Properties of PHB’s

<table>
<thead>
<tr>
<th></th>
<th>Physical properties</th>
<th>Mechanical properties</th>
<th>Thermal Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P(3HB) (Biomer PL9000)</td>
<td>P(3HB) (Biomer P226)</td>
<td>PHB Biocycle</td>
</tr>
<tr>
<td>Melt flow rate (g/10 min)</td>
<td>38</td>
<td>5–7</td>
<td>43.74</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>1.25</td>
<td>1.25</td>
<td>1.23</td>
</tr>
<tr>
<td>Tensile strength at yield (MPa)</td>
<td>24</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Elongation at yield (%)</td>
<td>2.4</td>
<td>19</td>
<td>1.89</td>
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<tr>
<td>Flexural Modulus (MPa)</td>
<td>35</td>
<td>1750</td>
<td>2710</td>
</tr>
<tr>
<td>HDT (°C)</td>
<td>56</td>
<td>96</td>
<td></td>
</tr>
<tr>
<td>Vicat softening point (°C)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Comparison of plastics for performance

![Graph showing comparison of plastics' performance](image-url)
Comparison of the energy content and GHG emissions of petro plastics and bio plastics

– Source data from Novamont Italy
Key Findings:

• Disposal of biodegradable bio-polymer has a small contribution to environmental impact.
• Incineration with electricity generation provides a net benefit.
• Composting is the best disposal option for a biodegradable polymer.
• When disposed to landfill a biodegradable polymer has the potential to generate more impacts than similar petrochemical plastics.
• The overall biodegradable bio-polymer environmental profile is better than the petrochemical plastic even when the biodegradable biopolymer is disposed of in its most environmentally damaging waste facility.

Source: A.E. Harris “the Development of Biodegradable Biopolymer packaging and Sustainable waste management in the UK”; Imperial College University of London 2004.
• Metabolix announces US$200m plant to make Polyhydroxyalkanoates with commercial production by 2008 in Clinton Ohio of 110 m pounds of product based on starch form wheat corn or potatoes. (18.01.07)
• Marks and Spencer announced a £200m plan to be carbon neutral in 5 years. It will involve the use of recycled PET and recyclable plastics for packaging clothing and carrier bags. (15.01.07)
• London Remade announce £3m capital support for plastics recycling sector (10.01.07)
• Lurgi wins contracts (€100m) from China for new Coal Technology for plastics production. (02.01.07)
• Italy passes law to phase out non-biodegradable bags by 2010. (02.01.07)
• Biodegradables set for 22% per year growth led by PLA which has 43% of the market at 50,000 tonnes. (29.01.07)
• The UK’s Department of Trade and Industry (DTI) has put £278,000 towards the £777,000 Combine project, which aims to develop high performance plant-derived plastics for structural parts, such as car doors and boat hulls. (Dec 21 2006)

• Minister for Science and Innovation Malcolm Wicks said the project is the next step in making cars greener. "That's not even mentioning the competitive advantage this kind of technology could have for the UK economy," he added.

• Gordon Bishop of NetComposites, said: "[The Combine project] aims to create products which are biodegradable, for the first time creating structural materials and products from renewable resources."
The Future

• Fossil Fuels will be the main basis for plastics due to the volume requirements

• Recycling is still only a minor consideration but a key source of lower cost materials.

• Collection of this “end of life” material is the key for the future.

• Recycling technology is ready

• The production capacity of Bio based polymers will increase from 50,000 tpa to 90,000 tpa by 2010 and will probably remain a speciality niche market in the near future.

  (BBC 10 Nov 2005)

Collection for BioPlastics?