Nova: Science in the news
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Making packaging greener – biodegradable plastics

Biodegradable plastics made with plant-based materials have been available for many years. Their high cost, however, has meant they have never replaced traditional non-degradable plastics in the mass market. A new Australian venture is producing affordable biodegradable plastics that might change all that.

Contents

Key text
- Box 1. Life cycle analysis

Activities
Further reading
Useful sites
Glossary

Key text

Our whole world seems to be wrapped in plastic. Almost every product we buy, most of the food we eat and the many of the liquids we drink come encased in plastic. In Australia around 1 million tonnes of plastic materials are produced each year and a further 587,000 tonnes are imported. Packaging is the largest market for plastics, accounting for over a third of the consumption of raw plastic materials – Australians use 6 billion plastic bags every year!

Plastic packaging provides excellent protection for the product, it is cheap to manufacture and seems to last forever. Lasting forever, however, is proving to be a major environmental problem. Another problem is that traditional plastics are manufactured from non-renewable resources – oil, coal and natural gas.

Plastics that break down

In an effort to overcome these shortcomings, biochemical researchers and engineers have long been seeking to develop biodegradable plastics that are made from renewable resources, such as plants.

The term biodegradable means that a substance is able to be broken down into simpler substances by the activities of living organisms, and therefore is unlikely to persist in the environment. There are many different standards used to measure biodegradability, with each country having its own. The requirements range from 90 per cent to 60 per cent decomposition of the product within 60 to 180 days of being placed in a standard composting environment.

The reason traditional plastics are not biodegradable is because their long polymer molecules are too large and too tightly bonded together to be broken apart and assimilated by decomposer organisms. However, plastics based on natural plant polymers derived from wheat or corn starch have molecules that are readily attacked and broken down by microbes.

Plastics can be produced from starch

Starch is a natural polymer. It is a white, granular carbohydrate produced by plants during photosynthesis and it serves as the plant's energy store. Cereal plants and tubers normally contain starch in large proportions. Starch can be processed directly into a bioplastic but, because it is soluble in water, articles made from starch will swell and deform when exposed to moisture, limiting its use. This problem can be overcome by modifying the starch into a different polymer. First, starch is harvested from corn, wheat or potatoes, then microorganisms transform it into lactic acid, a monomer. Finally, the lactic acid is chemically treated to cause the molecules of lactic acid to link up into long chains or polymers, which bond together to form a plastic called polylactide (PLA).

PLA can be used for products such as plant pots and disposable nappies. It has been commercially available since 1990, and certain blends have proved successful in medical implants, sutures and drug delivery systems because of their capacity to dissolve away over time. However, because PLA is significantly more expensive than conventional plastics it has failed to win widespread consumer acceptance.

Plastics can also be produced by bacteria

Another way of making biodegradable polymers involves getting bacteria to produce granules of a plastic called polyhydroxyalkanoate (PHA) inside their cells. Bacteria are simply grown in culture, and the plastic is then harvested. Going one step further, scientists have taken genes from this kind of bacteria and stitched them into corn plants, which then manufacture the plastic in their own cells.

What’s the cost?

Unfortunately, as with PLA, PHA is significantly more expensive to produce and, as yet, it is not having any success in replacing the widespread use of traditional petrochemical plastics.

Indeed, biodegradable plastic products currently on the market are from 2 to 10 times more expensive than traditional plastics. But environmentalists argue that the cheaper price of traditional plastics does not reflect their true cost when their full impact is considered. For example, when we buy a plastic bag we don’t pay for its collection and waste disposal after we use it. If we added up these sorts of associated costs, traditional plastics would cost more and biodegradable plastics might be more competitive (Box 1: Life cycle analysis).

Biodegradable and affordable

If cost is a major barrier to the uptake of biodegradable plastics, then the solution lies in investigating low-cost options to produce them. In Australia, the Cooperative Research Centre (CRC) for International Food Manufacture and Packaging Science is looking at ways of using basic starch, which is cheap to produce, in a variety of blends with other more expensive biodegradable polymers to produce a variety of flexible and rigid plastics. These are being made into ‘film’ and ‘injection moulded’ products such as plastic wrapping, shopping bags, bread bags, mulch films and plant pots.

Mulch film from biodegradable plastics

The CRC has developed a mulch film for farmers. Mulch films are laid over the ground around crops, to control weed growth and retain moisture. Normally, farmers use polyethylene black plastic that is pulled up after harvest and trucked away to a landfill (taking with it topsoil humus that sticks to it). However, field trials using the biodegradable mulch film on tomato and capsicum crops have shown it performs just as well as polyethylene film but can simply be ploughed into the ground after harvest. It’s easier, cheaper and it enriches the soil with carbon.

Pots you can plant

Another biodegradable plastic product is a plant pot produced by injection moulding. Gardeners and farmers can place potted plants directly into the ground, and forget them. The pots will break down to carbon dioxide and water, eliminating double handling and recycling of conventional plastic containers.

Different polymer blends for different products

Depending on the application, scientists can alter polymer mixtures to enhance the properties of the final product. For example, an almost pure starch product will dissolve upon contact with water and then biodegrade rapidly. By blending quantities of other biodegradable plastics into the starch, scientists can make a waterproof product that degrades within 4 weeks after it has been buried in the soil or composted.

Landfill sites aren't compost heaps

To maximise the benefit of the new bioplastics we'll have to modify the way we throw away our garbage – to simply substitute new plastics for old won't be saving space in our landfills.

Although there is a popular misconception that biodegradable materials break down in landfill sites, they don't. Rubbish deposited in landfill is compressed and sealed under tonnes of soil. This minimises oxygen and moisture, which are essential requirements for microbial decomposition. For biodegradable plastics to effectively decompose they need to be treated like compost.

Composting the packaging with its contents

Compost may be the key to maximising the real environmental benefit of biodegradable plastics. One of the big impediments to composting our organic waste is that it is so mixed up with non-degradable plastic packaging that it is uneconomic to separate them. Consequently, the entire mixed waste-stream ends up in landfill. Organic waste makes up almost half the components of landfill in Australia.

By ensuring that biodegradable plastics are used to package all our organic produce, it may well be possible in the near future to set up large-scale composting lines in which packaging and the material it contains can be composted as one. The resulting compost could be channelled into plant production, which in turn might be redirected into growing the starch to produce more biodegradable plastics.

An Olympic effort – recycling 76 per cent of waste

For anyone who thinks such schemes aren't feasible, you only have to look at the recycling success of the Sydney Olympics to see that where there's a will, there's a way. More than 660 tonnes of waste was generated each day at its many venues. Of this, an impressive 76 per cent was collected and recycled. Part of this success was due to the use of biodegradable plastics used in the packaging of fast food, making the composting of food scraps an economic proposition as it eliminated the need for expensive separation of packaging waste prior to processing.

With intelligent use, these new plastics have the potential to reduce plastic litter, decrease the quantities of plastic waste going into landfills and increase the recycling of other organic components that would normally end up in landfills.

Box 1. Life cycle analysis

Life cycle analysis seeks to identify the true environmental impact of a product by considering its environmental effect at every stage of its ‘life cycle’. This includes the impact of extracting the raw materials, processing them into a product, transporting that product, using it and then disposing and/or recycling it. It attempts to quantify all of the material and energy inputs and all of the outputs of a product or process.

Environmental costs

Many environmentalists believe the price we pay for a product should reflect its 'life cycle' cost. Traditional plastic packaging is an example where the environmental cost is not reflected in the price we pay for the product. It is relatively cheap to manufacture and this is reflected in its inexpensive price. But this doesn’t factor in the costs of disposing of the plastic, its impact on wildlife or the large volume of landfill it takes up.

Recycling

Recycling schemes sound good are they economic when you take into account the resources consumed in transporting, processing and reworking the material to be recycled? At this stage there are no rigorous environmental studies on plastic that take into account greenhouse gas emissions, air pollution or energy consumption.

Quantitative or qualitative analysis

Life cycle analysis, often referred to as ‘cradle to grave’ analysis, is great in concept, and central to any sound approach in ecodesign. In practise, however, it’s difficult to apply quantitatively because there are no universal standards of comparison and many of the costs are impossible to define precisely. For example, what is the long-term impact of generating more carbon dioxide when we still don’t know the basic mechanics of global climate change.

However, even when applied qualitatively, and acknowledging our imperfect knowledge, life cycle analysis quickly demonstrates that the price we pay for a product often bears no relation to the environmental cost of creating it. Sustainability is all about taking this into consideration.

Related sites

- Life cycle analysis and assessment (Global Development Research Center, Japan)
- Environment management tools – life cycle assessment (United Nations Environment Programme)

Activities

- **CyberScience (CSIRO Australia)**
  - Problems with plastic and how to spot PVC – students use a copper wire and a burner to determine if a plastic is PVC.
- **South Australian Department of Education Training and Employment**

    - Investigating plastics – a unit of work that includes an experiment to identify plastics by determining density and melting properties.

- **Land Learn, Victorian Department of Primary Industries, Australia**
    - A whey to make biodegradable plastic – students investigate the synthesis of PHB and its degradation by bacteria. Students also discuss responsible waste management, recycling and ways to reduce their ecological footprint.

- **Berkeley Lab (University of California, USA)**
    - Polymer modelling activity – students use paper clips to model the linking of polymers.

- **Michigan Reach Out! (University of Michigan, USA)**
    - Playing with polymers – students use cooked spaghetti to model a polymer, and make a polymer using white glue, talcum powder and borax.

- **The Dow Chemical Company and the National Science Teachers Association (USA)**
    - Density determination of plastics – a more accurate density determination using a titration method.

- **Science and Mathematics Initiative for Learning Enhancement (Illinois Institute of Technology, USA)**
    - World of plastics and polymers – students make and investigate polymers.
    - Polymers – students make nylon fibres by layering two chemical solutions.

- **Organic and biochemistry (Mansfield University of Pennsylvania, USA)**
    - Plastics analysis – students examine some physical and chemical properties of some recyclable plastics and identify two unknown plastics.
    - Preparation of polymers – how to make polystyrene, nylon and slime.

Further reading

Ecos
No. 108, 2001, pages 4-5
Green plastic (by Wendy Pyper)
Describes biodegradable plastic products being developed in Australia.

No. 108, 2001, pages 4-5
Green plastic (by Wendy Pyper)
Describes biodegradable plastic products being developed in Australia.

New Scientist
8 October 2005, page 6
Cigarette butts go green
Describes compostable cigarette filters.

8 January 2005, page 11

Seabirds ingest bellyfuls of plastic pollution (by Rob Edwards Texel)
Reports on a study looking at plastics found in the stomachs of seabirds.

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11 September 2004, page 30
Battle of the bag (by Caroline Williams)
Looks at consumer attitudes to plastic bags.

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6 May 2004
Rising tide of micro-plastics plaguing the seas (by Maggie McKee)
Reports on a study looking at the amount of microscopic plastic fragments in the ocean.

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23 November 2002
Food scraps make perfect plastic (by Ian Sample)
Discusses a biological reactor that converts food waste into a biodegradable plastic.

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25 November 2000, page 22
Drugs on tap from morning dew (by Nell Boyce)
Explains how vaccines and plastics could be produced by plants, then retrieved in their guttation fluid.

Inside Science (No. 50), 19 October 1991
Degradable plastics (by John Emsley)
Covers biodegradation and photodegradation of plastics.

Scientific American
27 February 2006
Bacteria turn styrofoam into biodegradable plastic (by David Biello)
Reports on the use of bacteria to turn styrofoam into PHA, a biodegradable plastic.

August 2000, pages 24-29
How green are green plastics? (by Tillman U. Gerngross and Steven C. Slater)
Covers the environmental pluses and minuses of making plastics using green plants.

Useful sites

Australian Broadcasting Corporation

- **The indestructables** (*Features*, 27 January 2005)
  Describes two types of plastic bags, how they can be recycled, biodegradable bags and some alternatives to plastic bags.
  http://www.abc.net.au/science/features/indestructibles/
- **Composting plastic** (*The Lab*, 5 February 2002) Discusses the Australian technology that created a biodegradable plastic from cornstarch.
  http://www.abc.net.au/science/news/enviro/EnviroRepublish_472701.htm

- **No bag thanks** (*The Lab*) Describes the problems caused by plastic bags and ways in which to ease the problem.
  http://www.abc.net.au/science/features/bags/default.htm

Packaging materials (Key Centre for Polymer Colloids, Australia)

A case study that covers the use of plastic as a packaging material and the search for replacements (eg, starch).
http://www.kcpc.usyd.edu.au/discovery/9.5.1/9.5.1_package.html

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Biopolymers from crops: their potential to improve the environment (Proceedings of the 11th Australian Agronomy Conference, 2003)

Discusses the possibilities of developing a biopolymer industry in Australia.
http://www.regional.org.au/au/asa/2003/c/11/michael.htm

Non-food crops: turning the corner? (e-zine, Royal Society of Chemistry, UK)

Discusses the potential of plant-derived chemical products and why so many basic chemicals are still primarily derived from fossil fuels.
http://www.chemsoc.org/chembytes/ezine/2000/evans_feb00.htm

Bacterial plastics (Department of Bacteriology, University of Wisconsin, USA)

A more technical look at the biodegradable plastics that are synthesised by bacteria.
http://www.bact.wisc.edu:81/ScienceEd/discuss/msgReader$10

How green are green plastics? (*Scientific American*, August 2000)

Looks at how plastics manufacturing affects the environment.
http://www.sciam.com/article.cfm?articleID=0000D61F-E193-1C73-9B81809EC588EF21&catID=2

Biodegradable plastics from renewable sources (Institute for Prospective Technological Studies, Spain)

Explains that environmental concern is turning attention to biodegradable plastics, and presents an overview of technologies that are becoming available. Also describes the need for standards, biodegradability labels and effective tests of compliance. Written with a European focus.
http://www.jrc.es/pages/iptsreport/vol10/english/Env1E106.htm

Glossary

biodegradable. Able to be broken down into simpler substances by the activities of living organisms and therefore unlikely to persist in the environment.

composting. Breaking down aerobically plant and animal material using microorganisms. For successful composting there must be sufficient water and air to allow the microoganisms to break down the material.

Material derived from the aerobic breakdown of plant or animal material by microorganisms.

culture. To grow microorganisms such as bacteria and fungi in a laboratory under controlled conditions.

decomposer organism. An organism, usually a bacterium or a fungus, that breaks down organic material into simple chemical components, thereby returning nutrients to the physical environment.

gene. The basic unit of inheritance. A gene is a segment of DNA that specifies the structure of a protein or an RNA molecule. (Nova)

greenhouse gas. A gas that is transparent to incoming solar radiation and absorbs some of the longer wavelength infrared radiation (heat) that the Earth radiates back. The result is that some of the heat given off by the planet accumulates, making the surface and the lower atmosphere warmer. For more information see (The greenhouse effect, CSIRO Atmospheric Research, Australia).

monomer. A molecule that can join with other molecules to form a large molecule called a polymer. A monomer is the smallest repeating unit in a polymer chain.

photosynthesis. The biochemical process in which green plants (and some microorganisms) use energy from light to synthesise carbohydrates from carbon dioxide and water.

polyhydroxyalkanoate (PHA). A biodegradable polymer produced by bacteria that has the qualities of plastic. At one extreme, PHAs share properties with polypropylene, and at the other end of the range, they are similar to natural rubber. For more information see Material: PHAs – polyhydroxyalkanoates (Design inSite, Denmark).

polylactide (PLA). A biodegradable polymer derived from lactic acid. Because this polymer is broken down in our bodies, it has biomedical applications (eg, sutures). For more information see Material: PLA – polyactide (Design inSite, Denmark).

polymer. A long molecule that is made up of a chain of many small repeated units (monomers). Examples of polymers include starch, DNA, protein and plastics. For more information see Background information for teachers – Introduction to plastics (Hands On Plastics, American Plastics Council).

tuber. A thickened short underground stem or branch formed by some plants (eg, potatoes) as a food storage organ. Each of the 'eyes' on a potato are buds that can grow into new roots and shoots.

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