Biopolymers from crops: their potential to improve the environment

David Michael

Wondu Holdings, P.O. Box 1217, Bondi Junction, NSW 1355.
http://www.wondu.com/, dmichael@wondu.com

Abstract

Development of a bio-plastics industry in Australia has potential to benefit the environment and Australian agriculture by creating new markets for existing and new crops and increased competition at the farm-gate. Bio-plastics might also benefit the Australian plastics industry a lot more than it currently thinks it would! The worldwide interest in renewable resources, reduced greenhouse gas emissions and more efficient and effective management of waste has created renewed interest in bio-plastics. The immediate problem for Australia is the bio-plastics industry doesn't exist here. But the raw materials, plant breeding expertise, molecular scientists and biochemists are here to develop one. And there are over 2,000 synthetic plastic resin converters operating here. A systematic and coordinated industry development program, with significant investments in resin plants and strategic research is required.

Key Words

Bio-plastics, bio-polymers, PHA, PHB, biodegradable, PLA

Introduction

Over 99% of all plastics are produced or derived from the major non-renewable energy sources – crude oil, natural gas, naptha and coal – which are used as both an energy and feedstock material in processing. While agricultural materials have been considered for some time as a replacement energy source or feedstock substitute for plastics production they have for a decade or more fallen well short of expectations. The main general resistance to further use has been cost, followed closely by functionality [e.g. sensitivity to humidity for starch, brittleness for polyhydroxybuterate (PHB)] and lack of flexibility in producing specialised plastics materials. Nevertheless, as the world enters a century with new priorities for renewable energy and management of waste there is renewed interest in biopolymers and the efficiency with which they can be produced. New technologies in processing and plant breeding are helping to narrow the cost differential between synthetic plastics and bio-plastics, as well as improve material properties. Hanggi (1) describes the use of PHB in making thin walled, high strength plastic products of complex design. PHB can be produced by bacteria using traditional fermentation technology or more in plants themselves. Elsewhere, Plantic, an Australian company, claims to have the technology, through research undertaken by the CRC for International Food Manufacture, to produce both water resistance and biodegradability from starch-based biopolymers.

This paper describes, in brief, the results of an assessment of the potential for Australian agriculture to supply raw materials for a viable bio-plastics industry that would have an environmentally superior performance to the existing fossil fuel dominated industry.

Methods

The paper reviews the information available on environmental performance of bioplastics in the context of Australian resources to produce the materials for them. One of the complications in examining the potential for a bioplastics industry in Australia is that there is no existing industry, though a small quantity of biodegradable resins (derived from both synthetic and natural materials) have been imported for local converters. From the perspective of Australian agriculture, however, it is in supplying raw materials for the resin market that is of most interest. There are four reasons why Australian agriculture would benefit from having a local bioplastic resin processing industry as distinct from just setting up to sell commodities for processing elsewhere, like it does now with a large proportion of the major grains for food. First, the bio-plastics industry, unlike the food industry, is not developed to any extent in any other countries. There are no established markets. This means demand for the materials to make the bio-plastics resin is subject to more than the usual levels of risk and uncertainty. But it also means the markets may be more open than they are with food. That said, we should not also underestimate the risks and uncertainty of selling the bioplastic resin. Second, the viability of bio-plastics processing depends very much on containing costs, including transport costs. This means local processing may have a natural advantage when compared to processing in distant locations, especially if low valued bulky waste materials are used as substrates. Moreover, Australia is a recognized international producer of low cost agricultural crops. The third reason is that vertically integrated supply chains have proven to be effective in moderating transaction risks faced by independent operators in disjointed supply chains where there are undeveloped markets and high risks in dealing between successive processing and production stages. The final reason is that Australia seems to be well placed to set up what we might call the optimal environmental business model (s) for producing bio-plastics. This is because it has the resources and doesn't subsidise production of agricultural crops. Production subsidies have an inherently negative impact on the environment because they encourage energy intensive land management practices.

These bio-plastics models might be based on various low cost, less intensive crop materials (from waste to whole grains), with support from scientists in plant breeding, fermentation and extraction technologies, coupled to a few serious investments in bio-plastics resin production.

Results

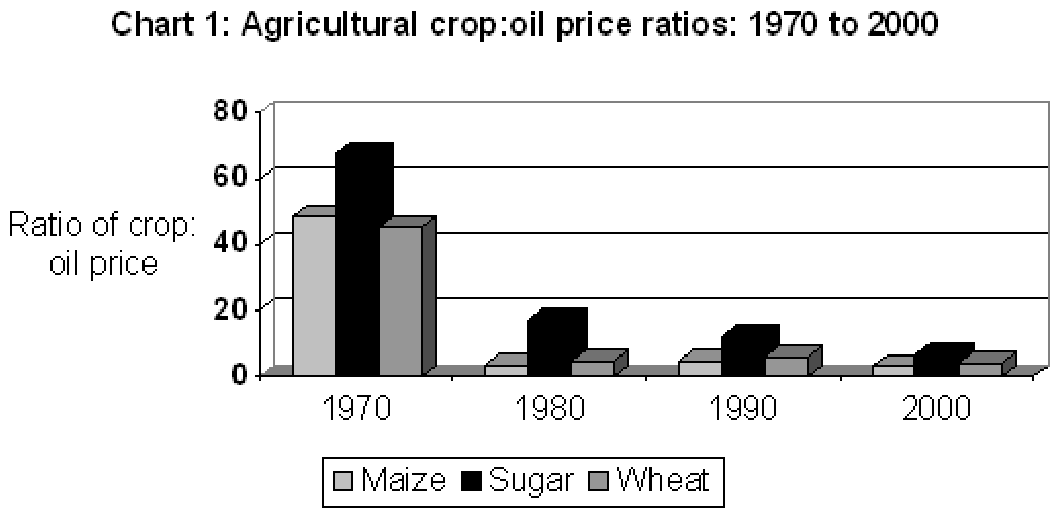
The Market

For the next 10 years the market for plastics is expected to continue the rapid growth it experienced in the last half of the last century. World per capita consumption of plastics is expected to increase from the current level of 24.5 kg to 37 kg by 2010 led by the US, Western Europe and Japan, but South-east and East Asia and India are expected to emerge as growth regions to account for 40% of world consumption of plastics by 2010. World consumption is expected to increase form the current 180 million tonnes to 258 million tonnes in 2010. All plastics resin categories are expected to experience significant positive growth as further substitution takes place with traditional materials like steel, wood and glass.

Australian manufacturers (who produce only synthetics), however, are expected to be seriously challenged in meeting the growth opportunities for resins in both domestic and export markets. As a result the Australian trade deficit in plastics is expected to grow significantly to more than $4 billion/year by 2010.

The possible market share for bio-plastics in Australia could range from 10% to 30% of the polyethylene (PE) resins used in packaging and for making products for agriculture itself. This would translate to 41,000-123,000 tonnes by 2010. The world market for biopolymers could be between 4 million and 12.5 million tonnes by 2010, an estimate, which, it is emphasised, could be well over or well under the actual outcome, depending very much on the level of R&D applied to developing new bio-plastics resins. This implies, somewhat conservatively, that bio-plastics could capture between 1.5 and 4.8% of the total plastics market. To penetrate the plastics market a bio-plastics producer would need to recognize and deal systematically and comprehensively with several key issues: a.) economies of scale exist and are important in reducing unit costs; b.) access to low cost materials of consistent quality; c.) reliable supply and ability to accommodate market growth; d.) market segmentation for speciality plastics; e.) access to significant R&D resources to bring about continuous improvements in productivity; f.) supply chain coordination; g.) government regulations; and h.) investor sentiment, which might be seen as now favouring greater use of renewable resources, providing there is an improvement in energy efficiency and reduction in greenhouse gas emissions.

Irrespective of environmental benefits of bio-plastics the price of crude oil and naptha relative to agricultural materials will continue to have a significant influence on the competitive position of bio-plastics viz. synthetics, though continued improvements in agricultural material production and processing technologies also have potential to further narrow the traditional cost advantage of synthetics. Over the past 30 years the price ratio of agricultural materials:crude oil [$/t:$/barrel] has declined significantly. This price ratio decline seems likely to continue and narrow the gap between the prices of synthetic and bio-plastics resins.



Production Possibilities

The production of 41,000-123,000 tonnes of resins for packaging and agricultural inputs such as films would require an estimated 105,000-316,000 tonnes of, for example, maize to produce polylactic acid (PLA). An optimal sized PLA plant of 140,000 tonnes/year would require an estimated 350,000 tonnes of maize or equivalent wheat, sorghum etc.

After examining research and product development of bio-plastics it seems that the main objective in much of the research has been about the function of biodegradability, with all other issues including energy efficiency and emission reduction of secondary concern. Yet for some bio-plastics energy efficiency and emission performance are among their strongest virtues and biodegradability is not always the most sought attribute. Also, the essence of the matter of biodegradability is being address, in part at least, with elaborate recycling of synthetic polymers and even the emergence of biodegradable synthetics. The real game is about materials performance, sustainability, use of renewable energy and decreased emissions.

Patel (2) concluded it '… is impossible to make a general statement about whether plastics from biomass are favourable in terms of energy loss and CO_2 emissions compared to petrochemical polymers.' Some bio-plastics such as the natural bacterial based polyesters, polyhydroxyalkanoate (PHA) and its offspring such as PHB, appear to be relatively less energy inefficient as feedstock (though still quite good compared to petrochemical polymers) while starch based polymers offer the potential to both save on energy and reduce CO_2 emissions. According to Patel, depending on the share of petrochemical co-polymers used, starch based plastics offer energy and emission savings of 12-40 GJ/t plastic and 0.8-3.2 t CO_2 plastic in producing PE or an equivalent biodegradable substitute.

The increased energy consumption and CO_2 emissions associated with an increased share of synthetics in the resin is shown clearly in Table 1. These estimates have been compiled by Patel from various life-cycle assessments done in Western Europe and North America. The energy use is non-renewable energy and GHG emissions are expressed in terms of CO_2 equivalents. There is no allowance for the carbon sink effect of the plants that produced the starch, so the environmental benefits are probably understated.

Table 1: Emissions and Energy Use: Thermoplastic Starch and Synthetics

Type of Plastics	Share of Petrochemical Compounds % (wt)	Cradle to factory gate energy use [1] (Gj/t of product).	Fossil CO_2 emissions throughout life-cycle (production & waste incineration) (kg CO_2)/t product.
TPS	0	25.4	1,140
TPS/polyvinyl alcohol	15	24.9	1,730
TPS/polycaprolacton	52.5	48.3	3,360
TPS/polycaprolacton	60	52.3	3,600
LDPE	100	80.6	4,840

[1] Non-renewable fossil and nuclear energy
Source: Patel (2).

The diversity of plant, animal, microbial and marine materials that are used to produce the above materials is also significant. For this reason, bio-plastics may also be seen as conducive to biodiversity because the industry has potential to use such a wide range of genera and species. Also, bio-plastics have potential to use the products of perennial plants that are being used to solve environmental problems like salinity.

Market penetration by bioplastics, however, may require a fundamental change in attitude in large parts of the chemicals and plastics industry. Environmental concerns, along with biodegradable polymers, are seen by many as just another threat to the traditional industry, rather than a stimulating challenge, to those who practice plant breeding and the chemistry of plastics in industry, education and research and marketing of the products. The threat mentality extends up the supply chain to waste management regimes where biodegradability is seen as an obstacle to existing recycling practices and down the supply chain to agricultural material production where there is an historical preoccupation with the food supply chain in plant production and lack of recognition that industrial product uses for agricultural crops offer benefits in the form of increased competition at the farm gate and access to growth markets instead of mature markets.

One step in bringing an appropriate level of resources to a new bio-plastics industry would be to establish a Centre of Excellence in Bio-plastics. The objective of the Centre would be to develop opportunities for suppliers of agricultural materials as feedstock and energy for the production of biodegradable and non-degradable plastics. Plant breeders, chemists and plastics converters would be needed to design and develop a range bio-plastics resins with high performance in terms of material properties and environmental attributes.

Conclusions

This paper basically concludes in favour of the development of a bio-plastics industry, but it would need to be one with high environmental performance, as well as achieving new standards of functionality in materials performance. Agronomists, plant breeders and industrial chemists have the potential to deliver these outcomes.

References

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