Part I

1

Introductory Overview

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1.1 INTRODUCTION

This book presents the latest knowledge about the synthesis and properties of bio-derived polymers in terms of practical film and coating applications. These biopolymers include starch, polyactides (PLAs), polyhydroxyalkanoates (PHAs), chitosan, proteins, hemicelluloses, cellulose and furan polymers. The contents are divided into two parts: Part 1 in which the synthesis or production and properties of biopolymers are discussed and Part 2 in which specific applications are covered. With this structure, the objective of the book is to provide the reader with an up-to-date summary of current knowledge concerning individual biopolymers and then to discuss the state of their development and uptake in a number of key fields, including packaging, edible films and coatings, paper and paperboard, and agronomy. A further chapter deals with specialized uses of biopolymers in optoelectronics and sensor technologies, a field which is still very much in its infancy. In this introductory overview, biopolymers and the question of sustainability are discussed in the context of total world markets for plastics and resins.

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1.2 WORLDWIDE MARKETS FOR FILMS AND COATINGS

1.2.1 Total Polymer Production and Use

In order to set the scene for this book, it is useful to get a sense of the total volumes and types of polymer used worldwide as well as in use specifically in films and coatings. This includes such everyday materials as kitchen films, grocery carrier bags and garbage bags, and many types of industrial and specialty films, as well as industrial or architectural paints and coatings. Since polymer production and consumption is reported in various ways, it can be difficult to separate out uses in films and coatings from total polymer usage; however, some insights can be gained through reports from industry associations and other sources.

A RAPRA report from 2004 [1] states that in 2003 the total global consumption of polymers in solid form (i.e., not adhesives, paints, binders) was 160 million tonnes and, of this amount, about 40 million tonnes was in the form of films. Information presented by Ambekar *et al.* [2] illustrates the steady increase in total plastics consumption over the past 50–60 years and indicates that this figure reached 260 million tonnes in 2007, of which about one-third was used in packaging. Volumes of plastics produced worldwide according to figures for 2007 are shown in Figure 1.1. According to the American Chemistry Council (http://www.americanchemistry.com), US production of thermoset resins in 2009 was 12.7 billion pounds on a dry weight basis, down nearly 16% from 2008, probably as a result of the impact of the economic crisis on construction activity. The corresponding figure for thermoplastic production in 2009 was 86 billion pounds which reflected only a 0.5% decrease over 2008, possibly because of the greater diversity of markets for thermoplastics as compared with thermosets.

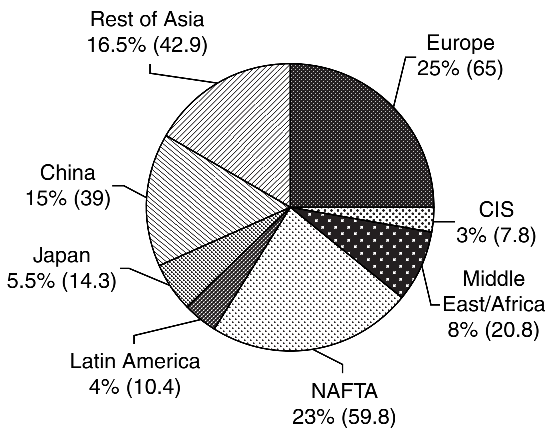

Figure 1.1 Volumes of plastics produced worldwide in 2007. Figures in brackets are millions of tonnes (*Source*: Plastics Europe Market Research Group)

Table 1.1 World polymer consumption in 2006 and projected consumption for 2016 (thousands of metric tonnes) [3]. Adapted from Accenture report "Trends in manufacturing polymers: Achieving high performance in a multi-polar world", 2008

Market sector	2006	2016
Construction	45 886	72 919
Plastic products	43 500	78 361
Food	42 025	71 774
Textiles	32 176	51 630
Electrical/electronic	13 810	25 499
Furniture	13 687	22 993
Vehicles and parts	10 746	15 625
Machinery	2397	3658
Fabricated metals	1519	2259
Printing	780	1220
Other transportation	9330	16 181
Other equipment	3852	6334
Other manufacturing	21 238	33569
Total	240 947	402 022

A report by the consulting company Accenture discusses polymer consumption by market sector in 2006 and consumption figures predicted for 2016 [3]. A summary of the relevant data is shown in Table 1.1.

1.2.2 Total Production and Use of Plastic Films

The world market for plastic films is dominated by polyethylene (PE) and polypropylene (PP), which together comprise some 34 million tonnes per annum. These polyolefins are subject to increasing demand as the main materials used in packaging films, particularly in the developing areas of the world. Besides PE and PP, polyethylene terephthalate (PET) film is used in packaging and in a wide range of industrial and specialty products, such as in electrical (e.g., transformer insulation films, thermal printing tapes) and imaging products (e.g., microfilm, x-ray films, business graphics). Polyvinyl chloride (PVC) films are found in consumer goods and medical applications and polyvinyl butyrate (PVB), because of its optical clarity, toughness, flexibility and ability to bind to many surfaces, is mainly used in automotive and construction applications as glazing protection. Polystyrene (PS) films are also used in packaging and a variety of other medical, commercial and consumer goods. The primary types of plastics used in films, their properties and various applications are shown in Table 1.2. Polymer films as a whole are a massive market sector with Europe and North America each consuming about 30% of total world production and increasing volumes being consumed in the growing economies.

Regardless of polymer type, packaging is the main end use for plastic films. In this context, films are generally defined as being planar materials less than 10 mils or $\sim$250 μm in thickness (i.e., thick enough to be self-supporting but thin enough to be flexed, folded and/or creased without cracking). Above this thickness, the term sheet is frequently used instead of film. Data from Plastics Europe (http://www.plasticseurope.org) confirm that packaging is the biggest end-use for

Table 1.2 Commodity thermoplastic films – their properties and applications (* in addition, trays produced by thermoforming films of PET, PE and other thermoplastics are widely used in the packaging industry). PET = polyethylene terephthalate, HDPE = high-density polyethylene, LDPE = low-density polyethylene, PP = polypropylene, PS = polystyrene, PVC = polyvinyl chloride, PVB = polyvinyl butyral

Polymer type	Properties	Applications*
PET	Clear and optically smooth surfaces, barrier to oxygen, water and carbon dioxide, heat resistance for hot filling, chemical resistance	Oveneable films and microwave trays, packaging films, industrial and specialty films
HDPE	Solvent resistance, higher tensile strength than other PEs	Grocery bags, cereal box liners, wire and cable coverings
LDPE	Resistance to acids, bases and vegetable oils, good properties for heat-sealing packaging	Bags for dry cleaning, newspapers, frozen bread, fresh produce and household garbage, shrink wrap and stretch film, coatings for paper milk cartons, and hot and cold beverage cups, wire and cable coverings
PP	Excellent optical clarity in BOPP films, low water vapour transmission, inert to acids, bases and most solvents	Packaging, electronics, kitchen laminates, furniture, ceiling and wall panels
PS	Excellent water barrier for short shelf-life products, good optical clarity, hard wearing	Packaging, electronic housings, medical products, interior furnishing panels
PVC	Biologically and chemically resistant	Packaging films, wire and cable coverings, waterproof clothing, roofing membranes
PVB	Adheres well to various surfaces, optically clear, tough and flexible	Laminated safety glass for use in automotive and architectural applications

plastics (38%), followed by building and construction (21%), automotive (7%), and electrical and electronic (6%). Other applications for plastics, which include medical and leisure, use 28% of the total production volume (Figure 1.2).

In addition to packaging, the myriad applications of polymer films include decorative wrap, form-fill-seal, blood bags, flexible printed circuits, bed sheeting, diapers, and in-mould decorating of car parts (to replace painting and provide a more durable surface coating) to name just a few. Carrier bags and garbage bags are big markets with significant imports into Europe. In construction, films are used in glazing, damp proofing, tarpaulins, and geomembranes.

Multi-material or mutli-layer films account for around seven million tonnes annually, with about 95% of this volume going into packaging. Multi-layer materials

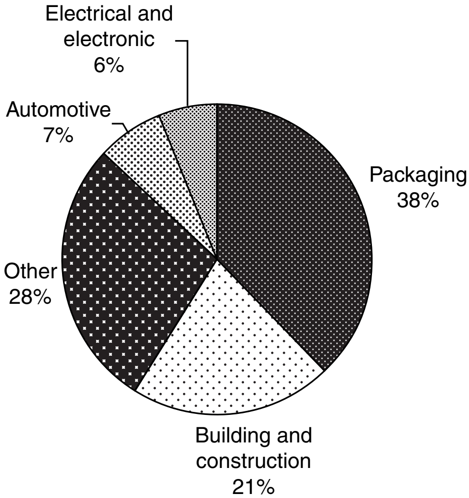

Figure 1.2 Plastics demand by converters in Europe in 2008. Total demand was 48.5 million tonnes (*Source*: Plastics Europe Market Research Group)

are attractive because they permit custom adaptation of properties such as barrier and strength. As well as the possibility to colour or print, and produce single or multi-layered products, films are also often combined with other materials such as aluminum or paper. An example is the aseptic packaging manufactured by Tetra Pak (Lund, Sweden) which contains layers of PE, paper and a very thin layer of aluminum acting as a water vapour and gas barrier. The introduction of technology such as orientation of PP films has also contributed significantly to the availability of more valuable film materials. In particular, biaxially oriented PP films (BOPP) have grown strongly on world markets because of their improved shrinkage, stiffness, transparency, sealability, twist retention and barrier properties.

According to Andrew Reynolds of Applied Market Information Ltd (http://www.amiplastics.com), the global agricultural film market consumed 3.6 million tonnes of plastic in 2007, of which roughly 40% was devoted to mulch films and a similar volume to greenhouse films. The remaining 20% was used in silage films.

Plastic films can be made via a number of well-established converting processes: extrusion, co-extrusion, casting, extrusion coating, extrusion laminating and metallizing. Blown extrusion was the first process used to make PE films. These processes have advantages and disadvantages, depending on the material in use, as well as the width and thickness of film required. Readers interested in the fundamentals of polymer processing are referred to recent textbooks on this subject [4, 5].

1.2.3 Coatings

In terms of industrial coatings, the world market for architectural paints is forecast to grow to 22.8 million metric tonnes, worth $51 billion, by 2013, according to a new report by The Freedonia Group, a Cleveland, Ohio-based industry consulting firm (http://www.freedoniagroup.com). On the basis of the large German industry, Europe is expected to remain the world's leading regional net exporter of architectural paint. The paint and coatings industry in North America, Europe and Japan is mature and generally correlates with the health of the economy, especially housing and construction and transportation. According to an industry overview published early in 2009 [6], annual growth rates of 1.5–2% were expected; however, the prolonged economic downturn in the West and in Japan will probably result in lower growth figures in the short term. The same report indicated good prospects for growth in the paint and coatings sector in the Asia-Pacific, Eastern Europe and Latin America. Growth of coatings in China was expected to continue at 8–10% per year and most multi-national paint companies have established production there.

Paper and paperboard represent large markets for polymer coatings in respect to printing, conversion and uses in packaging. Extruded coatings on paper and paperboard include those based on PE, PP, and PET, providing whiteness, smoothness and gloss. Functional coatings may also be used on paper and paperboard for grease resistance, water repellency, non-slip and release characteristics.

1.3 SUSTAINABILITY

In today's world, manufacturers are under pressure to satisfy varied, and often conflicting, demands such as lower costs, improved performance and enhanced environmental attributes. Material selection for a particular purpose can therefore be critical in a number of ways. As in many other industries, manufacturers and converters of polymer films and coatings now recognize the need to meet environmental demands and understand the need for sustainable manufacturing processes and products. In this context, there are now more and more efforts made to recycle and reuse plastics, even though total recycling is still far from adequate in many locations.

Concerning plastics recycling and disposal, with Europe as an example, converters used 48.5 million tonnes of plastics in 2008, down 7.5% on 2007, probably as a result of the first stages of the 2008–2009 financial crisis. Of all plastics used by consumers, 24.9 million tonnes ended up as post-consumer waste, up from 24.6 million tonnes in 2006, 51.3% of post-consumer used plastic was recovered and the remainder (12.1 million tonnes) went to disposal. Of the 51.3% recovered, 5.3 million tonnes was recycled as material and feedstock and 7.5 million tonnes was recovered as energy. The total material recycling rate of post-consumer plastics in 2008 was reported to be 21.3%. Mechanical recycling was 21% (up 0.9 percentage points over 2007) and feedstock recycling was at 0.3% (unchanged from 2007). The energy recovery rate increased from 29.2 to 30%.

The use of synthetic polymers has grown rapidly over the past few decades and is forecast to roughly quadruple by the year 2100 as a result of growing human population and prosperity. If this growth were to occur, we would need to use one-quarter of the world's current oil production just to manufacture plastics. Something – or a number of things – clearly must change. In this book we look at the issue of sustainability through opportunities to adopt increased use of bio-derived polymers from renewable sources as an alternative to traditional petroleum-based polymers. Biopolymers are now playing a significant, if still relatively small role, across a number of industries and can be viewed as sustainable in terms of variables such as raw material supply, water and energy use and waste product generation. Product viability, human resources and technology development also need to be viewed through the lens of sustainability. Since most biopolymers are either biodegradable or compostable, it can also be argued that bio-based polymers generally fit with the 'cradle-to-cradle' (C2C) concept in that, on disposal, they can become 'food' for the next generation of materials [7].

The achievement of true sustainability in any field requires a fine balance between environmental, economic and social concerns. In this respect, the life cycle assessment (LCA) approach can be especially useful [8, 9]. For the polymer industry as well as for consumers, a key question is the difference between 'bio-sourced' and 'biodegradable' and which is the more important. This question is complicated since most, but not all, bio-sourced polymers are biodegradable and some petroleum-sourced polymers are biodegradable. As a property, biodegradation can be viewed as an added feature for plastics, suited to certain specific uses and environments. Even if biodegradability is not necessarily a key market driver, the sourcing of polymers in a renewable way from biomass is increasingly in focus for industry and governments alike. As well as broad legislation in some countries requiring the introduction of bioplastics, particularly in grocery bags, cities such as San Francisco have taken steps to prohibit plastic carry bags completely, and similar steps are being considered elsewhere. In the food and beverage industry, McDonalds is using bioplastics packaging for the Big Mac sandwich and companies such as Biota (Telluride, Colorado) are making biodegradable water bottles.

Since bio-derived polymers are mostly sourced from biomass in one form or the other, it is useful to consider raw material supply. Unlike petroleum, biomass as a raw material for biopolymer production is widely available on a renewable basis. World biomass production is estimated at 170×10^9 metric tonnes per annum, of which 6×10^9 metric tonnes is said to be used by humans, with 2% for food, 33% in the form of wood for energy, paper, furniture and construction and 5% for non-food uses in areas such as clothing and chemicals [10].

The Sustainable Biomaterials Collaborative (SBC) based in Washington, DC has, in its 2009 guidelines for sustainable bioplastics, defined sustainable biomaterials as those that are: (1) sourced from sustainably grown and harvested croplands and forests; (2) manufactured without hazardous inputs and impacts; (3) healthy and safe for the environment during use; (4) designed to be reutilized at the end of their intended use; and (5) provide living wages and do not exploit workers or communities throughout the product lifecycle. The SBC is working to implement a new market-based approach connecting use of agriculturally derived biopolymers with best environmental practices on the agricultural land on which biopolymer production may essentially be based. The sustainability concept is then extended through biopolymer manufacturing (e.g., process safety, minimized emissions), the establishment of suitable infrastructure to compost, recycle or reuse products, and the development of appropriate new technologies for various markets (http://www.sustainablebiomaterials.org).

1.4 BIO-DERIVED POLYMERS

Current discussion on practical applications of bio-derived polymers generally focuses on bio-based thermoplastics, which are not only biodegradable or compostable, but are considered advantageous to the environment. Points that may be made in support of using bio-derived polymers can be based on: (1) the opportunity to close the carbon cycle by eventually returning plant-based carbon to the soil through biodegradation or composting and thereby reducing environmental impacts; (2) less use of fossil energy and reduced carbon dioxide emissions over manufactured product life cycles.

Market reports from the European Bioplastics Association (http://www.european-bioplastics.org) point to strong growth for bioplastics and suggest that this industry has been relatively resilient during the recent economic crisis. Evidence for this conclusion comes from investment in new plants, in new inter-company cooperation and, most importantly, from new innovations. Biopolymer industry growth has been strong in areas which have prospered relatively well during the economic crisis, but more mature markets in Europe and North America are also now predicted to grow. Outside of economic issues, challenges exist in some areas because some biopolymers, including PLA and PHA bioplastics, may not have the required technical properties to compete with conventional plastics in some applications. However, solutions are being developed and adopted by the industry, as in the use of heat-tolerant bio-based additives to improve thermal stability (e.g., collaboration between the US Agricultural Service and the plastics company Lapol based in Santa Barbara, California) [11]. This type of development may provide PLA films that can withstand high temperatures, to overcome one of the present drawbacks of the material. The impact resistance of PLA can also be enhanced through the use of impact modifiers and there are now developments in the use of non-bio-derived additives which can enhance both PLA processability and properties (e.g., Joncryl® ADR chain extender for PLA from BASF, Biostrength® 280 impact modifier from Arkema). In addition to the technical challenges associated with the processing and properties of biopolymers, commercial bioplastics are generally higher in cost than commodity petroleum-derived polymers. However, it is reasonable to expect that continued investment in R & D should ensure that bioplastics become technologically and economically more competitive over time.

The world's largest producer of PLA, NatureWorks LLC, has a production capacity of 140 000 tonnes per year and is in a strong market position in terms of the world's most widely used bioplastic with its Ingeo™ trade name. Ingeo™ biopolymers are already in successful commercial use in fiber and non-wovens, extruded and thermoformed containers, and extrusion and emulsion coatings. Among the material advantages, packaging products from Ingeo™ can be clear, opaque, flexible or rigid and offer gloss, clarity and mechanical properties which are similar to those of polystyrene. In an interesting example of customer feedback, the acoustic properties of PLA films used in packaging of snacks such as potato chips has recently been identified as a drawback and alternative less noisy materials are being developed. Other PLA manufacturers are Purac (Netherlands), Teijin (Japan), Galactic (Belgium), Pyramid Bioplastics (Germany), Zhejiang HiSun Chemical Co., Ltd (China), and Tong-Jie-Liang Biomaterials Co. (China).

Italy's Novamont, the leading European company and pioneer in the field of starch plastics, continues to expand its Mater-Bi® brand of starch-based materials with a reported 2009 capacity of 80 000 tonnes per year, which is forecast to double in the next three years. Novamont has recently announced plans to join forces with Thantawan Industry, a Thai packaging manufacturer, to distribute Mater-Bi® in Thailand. Mater-Bi® film is presently sold into markets for agricultural films, packaging and kitchen films. Cereplast Inc, based in California, is the largest starch plastic producer in the United States with two product lines, Cereplast Compostable™ and Cereplast Hybrid™. Other thermoplastic starch producers include Rodenburg (Netherlands), Biotec (Germany), Limagrain (France), BIOP (Germany), PaperFoam (Netherlands), Harbin Livan (China), Plantic (Australia) and Biograde (Australia).

The US company Metabolix Inc. has the highest profile in terms of manufacturing bacterial polyesters (i.e., PHAs). A joint venture has been established with the Archer Daniels Midland Company (ADM) and PHAs are now being produced and marketed through Telles, a joint sales company formed between Metabolix and ADM, under the Mirel™ trade name. The plans are to produce Mirel™ at 50 000 tonnes per year at a plant in Clinton, Iowa in the US (http://www.mirelplastics.com). A range of Mirel™ concentrates or masterbatches are available which meet standards for compostability and biodegradability. Furthermore, a black Mirel™ film is presently being tested for use in agricultural mulch films. Other PHA producers include Kaneka (Japan), Meredian Inc. (USA), Biomer (Germany), Tianan Biologic Material Co. Ltd (China) and Tianan Green BioSciences Ltd (China), which is a joint venture with DSM.

There are numerous other commercial developments in the biopolymer field, especially in the area of bioplastics. For example, Biome Bioplastics recently announced a strong, translucent, low-noise, flexible and biodegradable film with high renewable content. JC Hagen of Austria has also added biodegradable resins to its portfolio, which are suitable for blown film extrusion and thermoforming. FKuR's Bio-Flex is now being used as the world's first compostable soap wrapping for application in Umbria Olii's EcoLive brand of laundry soap. A glance at the web site http://www.biopolymers.net provides an idea of the many different companies involved in this field as well as the biodegradable, but not necessarily 100% renewable material-based, products from major companies such as BASF (Ecoflex®), Bayer (BAK®) and DuPont (Biomax®).

In 2007, bioplastics represented 0.1% of total world commodity plastics. The predicted capacity for 2012 is in the 500 000–1000 000 tonne range, which is still a small niche in the total plastics market, which was forecast to reach 220 million tonnes in 2010. The market focus varies from region to region. In the European Union, the main areas of use are fresh food packaging and carrier bags, while in Japan it is mainly durable goods and textiles. According to Pira (http://www.pira.com), global bioplastic packaging consumption was projected to reach 125 000 tonnes in 2010 with a market value of $454 million; however, a report from BCC Research (http://www.bccresearch.com) entitled "Bioplastics: Technologies and Global Markets" issued in September 2010 gives a figure of 571 712 metric tonnes for usage of bioplastics in 2010. A product overview and market projection for emerging bio-based plastics was commissioned by the European Polysaccharide Network of Excellence (EPNOE) (http://www.epnoe.eu) and European Bioplastics (http://www.european-bioplastics.org) and completed in June 2009 [10].

The successful commercial introduction of bio-based plastics depends upon various factors. Economically, the most important of these factors are the price of oil, the price of bio-feedstocks, investment risks, fiscal policy initiatives, and the availability of capital at competitive interest rates. Technologically, success typically depends upon the patent situation, the reliability of new technologies and the pace at which technology can be developed. Other issues determining success are the availability of trained personnel with knowledge of the sector, collaboration with companies in the agro-industry chain, the availability of raw materials and the usefulness of co-products. Finally, from a market pull perspective, the most important issue will be demand from retailers and producers of consumer goods, as influenced by the attitudes of consumers, policy makers and other stakeholders. Bio-based polymers represent a new era for the polymer manufacturers within the chemical industry and, although volumes are still low, the speed of development in this sector is relatively fast.

If we look at the most important current market for bioplastics (i.e., packaging), industry growth is likely to be motivated by issues such as consumers' positive interest in environmentally friendly materials, the introduction of sustainability programmes by retailers and brand owners to assist in product differentiation, growth in the availability of non-biodegradable plant-derived plastics, developments in terms of new suppliers and production capability, and industry or government initiatives aimed at certification, regulation and standards. Even the existence of bio-based, biodegradable plastics may be unknown to a broad swathe of the wider public, pointing to the need for more educational initiatives as well as continued product- and process-orientated R & D.

Seen from the present perspective, it would be a mistake to assume that all bio-derived plastics necessarily have a lower carbon footprint than conventional polymers or that bio-based production can in due course entirely replace the oil-based industry. Biopolymers are the basis of an industry which is still in an emerging phase and will only be successful if equal product functionality can be delivered at lower cost, new product functionality can be delivered at the right value for money or the footprint in the value chain can be improved. Although the bio-based polymer business was only a few tenths of a percent of the total polymer market in volume at the end of 2009, some predictions suggest that in the post-financial crisis world, the annual growth rate based on existing technologies could reach 20% by 2020. The introduction of new technological developments and new products could further increase this predicted growth rate.

1.5 OTHER TOPICS

It is important to note that there are a number of important topics which are necessarily outside the scope of this book on sustainable films and coatings. One of the most significant of these is the use of biomass, instead of petroleum derivatives, to manufacture conventional polymers. The prime example is the pioneering activity of the Brazilian company Braskem, which opened a commercial plant in Triunfo, Brazil in September 2010 to produce PE from sugarcane ethanol with an initial annual capacity of 200 000 tonnes. The Braskem process involves dehydration of ethanol to ethylene and then conversion to PE by traditional means. Interestingly, the first commercial plant to manufacture ethylene from ethanol was built and operated at Elektrochemische Werke GmbH in Germany as long ago as 1913 and from 1930 onwards ethanol dehydration plants were the sole source of ethylene in Germany, Great Britain and the United States. The seeds of the Braskem technology therefore go back many decades. Brazilian capacity for plant-based ethanol production is estimated at 25 billion litres in 2009 and is thought likely to have reached 28 billion litres in 2010. From a sustainability perspective, the World Bank and the FAO have confirmed that Brazilian ethanol has not raised sugar prices significantly and may be the only bio-fuel which is both competitive with petroleum-based diesel or gasoline and which saves on greenhouse gas emissions [12, 13].

The start-up of PE production by Braskem has attracted global interest because the PE produced by this method is for all practical purposes identical to that manufactured from petroleum. Braskem has already established agreements with Procter & Gamble, Toyota, Shiseido and Johnson and Johnson, and Tetra Pak has also recently announced trials using PE from Braskem in its packaging. While bio-based PE production is now starting, bio-based PP is still at the laboratory bench stage. However, at the end of 2009, Braskem established a partnership with the Danish company Novozymes to develop bio-based PP using Novozymes' core fermentation technology and Braskem's chemical technology and thermoplastics expertise. In another development, Dow and Crystalsev, a major Brazilian ethanol producer, announced a joint venture in 2007 with plans for bio-based PE production in 2011.

Industrial coatings and architectural paints for buildings are also generally outside the scope of this book. Manufacturers have for decades realized the need to use water-borne coatings where practically feasible and a transition to bio-derived resins in such coatings might eventually occur if the sort of technology being developed by Braskem and other companies was extended to allow manufacture of bio-alternatives to a wide range of other commonly used petroleum-derived resins (e.g., polyurethanes). In fact, bio-materials are already used to some extent in the coatings sector, for example in the case of hydroxyethyl celluloses. These non-ionic cellulose derivatives are universal thickeners for internal or external paints and coatings, preventing pigment settling, adding structural viscosity and water retention to paints and enhancing spreadability and water resistance. Medium-viscosity methyl hydroxyethyl cellulose and hydroxyethyl cellulose have been used in aqueous paints, whereas ethyl hydroxyethyl cellulose has been preferred for solvent-borne systems. In recent years, associative thickeners based on acrylate chemistry have been developed as an alternative to these cellulose ethers [14].

Life cycle assessment (LCA), although important in helping to clarify sustainability and cradle-to-cradle issues, is also not specifically addressed as a topic. The reader is therefore referred to a number of recent studies and books which have advanced knowledge in this area as it applies to biopolymers. LCA will no doubt continue to be very significant in terms of how industry and governments view bio-sourced materials and their overall contribution to future societies [10, 15–19].

Finally, the use of biopolymer films and coatings in medical-related applications, examples of which would include antimicrobial coatings for medical devices, treatment of wounds and burns, and films for dermal drug delivery, is not included as a specific topic in this book.

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