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Policies for Bioplastics in the Context of a Bioeconomy

OECD

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TABLE OF CONTENTS

FOREWORD....5
EXECUTIVE SUMMARY....6
INTRODUCTION....9
BIOPLASTICS: FROM RAW MATERIALS TO END-OF-LIFE OPTIONS....11
What is a bioplastic?....11
The life cycle of a bioplastic....11
Environmental and economic issues surrounding bioplastics....23
POLICY OPTIONS FOR THE DEVELOPMENT OF BIOPLASTICS....34
Supportive environments....34
Specific options for the development of bioplastics....35
POLICIES AND PRACTICES BY COUNTRY....39
Argentina....39
Brazil....39
Bulgaria....41
Canada....41
China....42
Denmark....43
France....43
Germany....43
Israel....44
Ireland....44
Italy....45
Japan....47
Korea....48
Malaysia....50
Netherlands....50
Norway....51
Spain....51
Sweden....52
Thailand....52
United Arab Emirates....53
United Kingdom....53
United States....54
European Union initiatives....57
CONCLUSIONS AND FUTURE WORK....67
Summary of policy trends....67
Key messages....69
Future work....69
ANNEX I – LIST OF ABBREVIATIONS....70
ANNEX II – LIST OF BIODEGRADATION AND COMPOSTING STANDARDS....71
NOTES....73
REFERENCES....75

Figures

Figure 1. Types of bioplastics, both biodegradable and non-biodegradable 11
Figure 2. Estimated life cycle emissions from biofuels.. 15
Figure 3. Relative costs in biorefinery operations for European sugar beet and Brazilian sugar cane 15
Figure 4. Development status of biorefinery concepts 16
Figure 5. Proportion of land required to substitute 20% of each energy source/material with bio-based alternatives.. 17
Figure 6. Predicted global production capacity of bioplastics... 18
Figure 7. Municipal waste treatment, Europe 2009.. 21
Figure 8. Biogas yields from various biopolymers.. 22
Figure 9. Calorie values of plastics, fuels and wastes (*(kcal per Nm^3 for natural gas and city gas) 23
Figure 10. Greenhouse gas emissions (as CO_2) for various petro- and biopolymers 25
Figure 11. Average non-renewable primary energy use and GHG emissions of bio-based chemicals in comparison to conventional chemicals.. 26
Figure 12. Number of firms in Canada by bioproduct type in 2009.. 31
Figure 13. Cost split for a mid-sized PLA plant.. 32
Figure 14. Biofuels production volumes mandated in RFS2... 57

Tables

Table 1. Recovery of phenanthrene in each phase in sorption experiments.. 27
Table 2. The Flemish bioeconomy 30

Boxes

Box 1. Italy - Substituting Traditional Plastic Carrier Bags with Biodegradable and Compostable Bags in Compliance with EN 13432. 45
Box 2. Case study: Billion Ton Study (US DoE, 2011) 56
Box 3. The European Union Advisory Group's main recommendations to promote bio-based products (Ad-hoc Advisory Group for Bio-based Products, 2009).. 61

FOREWORD

For several decades bio-based plastics have remained more or less in the research phase. With crude oil remaining relatively inexpensive, it was very difficult for any bio-based plastics to become established in the market. This century has seen some dramatic changes that have favoured further research and development of these novel plastics and more applications and new molecules are now emerging. Several factors have driven this rapid growth of the bioplastics industry. These are a combination of environmental, economic and social benefits that bioplastics offer in a time when crude oil prices seem set to remain high, and as we emerge from the greatest economic crisis of our lifetimes. The contribution of bioplastics to the entire plastics market is still small, but is growing very rapidly. This situation can present a quandary to policymakers. Rapid growth can often run ahead of policy making. It would therefore be timely for policymakers to have a document that shows the range of bioplastics being developed, but also the types of policies that have been applied to support this nascent industry. This report hopes to fulfil that need.

A major driver of the growth of the industry has been a transition from biodegradable plastics, used normally in simple packaging applications, to “drop-in” substitutes for the major oil-based plastics that dominate the market, upon which we rely so heavily today. A striking example of this is the development of bio-based polyethylene terephthalate (PET) bottles for carbonated drinks. The combination of bio-based content and the ability to enter established recycling infrastructure makes for a very attractive proposition in environmental and economic terms. Engineering applications of bioplastics are also increasing.

However, it is quite obvious that support for bioplastics has been very limited compared to, say, biofuels. And yet both categories of bio-based products aim to fulfil common policy goals. Indeed, there is evidence that bioplastics offer greater job creation and value-added than biofuels. There is no international pattern of support for bioplastics, except that the niche policy of banning single-use carrier bags has received widespread attention. Compared to the major policies that have been applied to biofuels, such niche policies will not stimulate the investments needed for large-scale production and market uptake.

There are still formidable hurdles for bioplastics to overcome. Within the context of holistic bioeconomy strategies, there is scope for the more considered use of intelligent policy mixes targeted at the development of bioplastics over their whole ‘cradle-to-grave’ life-cycle, and in concert with other bio-based products, especially biofuels.

It would be difficult to imagine a more successful category of materials than plastics. In the future, the very success of plastics may bring them into competition for crude oil with other applications. Greater policy support now will make later transitions from fossil to bio-based resources an easier task.

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EXECUTIVE SUMMARY

Bioplastics production, though small, is growing rapidly, with many new products and applications emerging as a consequence of intensive research and development (R&D) efforts. New production capacity is being installed by several companies across the globe, and bioplastics have attracted the attention of policymakers because of their use of renewable resources and the implications for sustainable development, particularly within the context of an emerging policy focus on the bioeconomy. Current interest therefore centres on:

- The potential economic, social and environmental benefits (and costs) of bioplastics;
- Barriers to the growth of a bioplastics industry; and
- The policy mechanisms needed to ensure that society reaps the rewards of developments in this sphere.

The evolution of the industry reflects in large part the emergence of new plastics and applications and can be envisaged in terms of three phases:

- The first phase was characterised by a single focus on biodegradable and/or compostable plastics, primarily intended for simple packaging applications.
- The second phase had an increasing focus on so-called second generation bio-based plastics (which are essentially improvements on the first generation in terms of performance and are broadly comparable to the bulk production plastics that are used in packaging applications). Second generation bioplastics have reached industrial scale production but are still at a price disadvantage relative to petro-plastics.
- The third phase and latest phase has seen the advent of third generation bio-based plastics (or bioplastics) that are far more durable. Third generation bioplastics are generally bio-based equivalents of the major thermoplastics that dominate the market – polyethylene (PE), polypropylene (PP) and polyethylene terephthalate (PET), with bio-based equivalents of polyvinyl chloride (PVC) expected soon. Phases one and two are still applicable: phase three did not replace the others.

In the current and foreseeable future, therefore, bioplastics are likely to comprise a mix of both biodegradable/compostable bioplastics and durable bioplastics.

The attractiveness of bioplastics as replacements for petro-based plastics is dependent in part on their ability to meet environmental as well as economic goals. Bioplastics, as well as other bio-based products, are of high societal, environmental and economic interest due to:

- Their use of renewable resources, resulting in the lower dependency of plastics on increasingly expensive fossil resources;
- Their potential ability to reduce greenhouse gas emissions throughout their lifecycle, compared with petro-plastics, and the potential for more sustainable industrial production of plastics (by, for example, reducing greenhouse gas (GHG) emissions);
- Their potential to offer more end-of-life options than petro-plastics and other materials, often including high biodegradability or compostability (for first and second generation bioplastics);
- Their scope to enhance industrial competitiveness through new innovative eco-efficient bio-based products and applications;
- The higher job creation potential of bio-based products compared with that for biofuels.

Despite these potential benefits, there are also many actual and potential barriers to the growth of a bioplastics sector. These include:

- Debates over the relative merits of using land to produce crops for non-food use rather than food use;
- Restricted access to adequate sources of biomass in countries with limited land resources and consequent dependence on international trade in biomass;
- Competition for biomass from more established sectors such as the biofuels sector, which also benefits in many countries from preferential policy regimes that disadvantage rival sectors such as bioplastics;
- Production costs that are currently higher than those for petrochemicals, though the differentials are rapidly becoming smaller;
- The possibility of public resistance to the use of technologies such as synthetic biology in advanced bioprocessing facilities (e.g. consolidated bioprocessing (CBP) plants);
- Inadequate recycling and disposal infrastructures for both biodegradable and durable bioplastics leading, for example to the accumulation of plastics and ‘microplastics’ in the environment, particularly the marine environment;
- Lack of standardisation and limited harmonisation of standards internationally concerning terms and concepts such as sustainability, which could act as a barrier to international trade;
- Lack of consensus on the methodologies needed to perform life cycle analyses (LCAs), preventing adequate assessments of the potential of bioplastics to reduce greenhouse gas emissions.

Many policies and policy instruments have the potential to affect the development of the bioplastics sector. These include agricultural policies, R&D support policies and trade and industry policies, and mechanisms such as subsidies and tax incentives, quota systems, standardisation schemes and regulatory measures. Looking across countries, the following characteristics and trends are apparent:

- Few countries have policies specifically targeting the bioplastics sector, whereas a number of countries have policies that nurture the biofuels and bioenergy sectors, which places bioplastics at a disadvantage in the competition for biomass;
- The only bioplastic policies that are widespread relate to the use and disposal of plastic bags;
- Many countries have R&D and innovation-related policies from which the bioplastics sector can benefit;
- A number of countries are making significant efforts to build up bioplastics production capacity, though the costs of scale-up associated with leading-edge facilities are a constraint;
- Large blocs such as the United States and the European Union have realised the potential of public procurement to stimulate market development;
- There is a growing interest in the development of comprehensive bioeconomy strategies in many countries around the world, with scope for targeted bioplastics initiatives with them.

Key messages for the policymaking community are as follows:

- Bioplastics have an important role to play in the development of the bioeconomy due to their potential to address environmental and economic challenges;
- Within the overarching context of the development of comprehensive bioeconomy strategies, the practice of according preferential treatment to sectors such as biofuels, which places bioplastics at a disadvantage, could be reconsideration;
- Again within the context of holistic bioeconomy strategies, there is scope for the more considered use of intelligent policy mixes targeted at the development of bioplastics over their whole ‘cradle-to-grave’ life-cycle; and
- Greater efforts are needed at an international level concerning the definition and harmonisation of standards related to concepts such as sustainability in order to avoid creating barriers to the international trade of bio-based products and bioplastics in particular.

INTRODUCTION

The bio-based economy (bioeconomy) first emerged as a policy concept within the OECD at the start of the 21st century. It linked advances in biotechnology to innovation and "green growth" via the use of renewable biological resources and innovative bioprocesses in industrial scale biotechnologies, firstly to produce sustainable products, jobs and income (OECD, 2001), and secondly to address global challenges such as climate change. In 2009, the OECD stated that the bioeconomy "can be thought of as a world where biotechnology contributes to a significant share of economic output" (OECD, 2009a), and the OECD publication *Towards Green Growth* provided recommendations to help governments identify policies with the potential to achieve the most efficient shift to greener growth (OECD, 2011b).

Numerous countries are now moving towards the implementation of national bioeconomy strategies. In February 2012, for example, the European Commission revealed its vision for the future in the report *Innovating for Sustainable Growth: a Bioeconomy for Europe* (European Commission, 2012a).[1] In this strategy, significant growth is expected to arise from sustainable primary production, food processing, industrial biotechnology and biorefineries. In turn, this is expected to lead to new bio-based industries, transform existing ones and open new markets for bio-based products.

Also in early 2012, the US government released its *National Bioeconomy Blueprint*,[2] with two stated purposes: to lay out strategic objectives that will help to realise the full potential of the US bioeconomy and to highlight early achievements toward those objectives. It envisages "a previously unimaginable future" in which two of the categories of new materials are: *i)* "ready to burn" liquid fuels produced directly from CO_2; and *ii)* biodegradable plastics made not from oil but from renewable biomass (The White House, 2012).

The use of plastics is now ubiquitous. Twenty times more plastic is produced today than fifty years ago, and plastics production worldwide has surpassed that of steel and continues to grow. The bulk of this production, however, is derived from oil, and degradation of conventional plastics (e.g. via incineration) releases carbon dioxide to the atmosphere that has been locked in fossil fuels for millennia. In contrast, bioplastics are based on renewable resources and the capture and release cycles for carbon dioxide are thus very short.

Bioplastics are conceptually not new but the discovery, after World War II, of large crude oil reservoirs halted the growth in their development as they could not compete on price with fossil-derived plastics. Today, the total production volume of bioplastics remains small compared with petro-plastics, which have enjoyed several decades of research and development to enhance the effectiveness and efficiency of their production. Worldwide consumption of all polymers reached about 259 million tonnes in 2012, with biopolymers representing 0.4% at 890,000 tonnes (Smithers Rapra, 2012).

From this small base, however, bioplastics production is expanding. A comprehensive market survey of bioplastics (Ceresana Research, 2009) estimated that, in the years 2000 to 2008, worldwide consumption of biodegradable plastics based on starch, sugar and cellulose – so far the three most important raw materials – increased by 600%. Moreover, according to a survey of the bioplastics industry by Shen et al. (2009), some companies reported growth rates of up to 50% per annum and production for the sector as a whole is expected to grow by an average of 19% per year between 2007 and 2020, production in 2020 being estimated at 3.45 million tonnes.

Given the expected growth of the bioplastics sector and the stress put on the development of bioplastics in some of the bioeconomy strategies that are currently emerging across the globe, it is timely to review some of the policy implications associated with their development and use, the types of policy instruments that could play a part in the creation of a supportive environment for bioplastics, and the range of policies currently in use that affect their production, diffusion and use.

The next section of this report thus looks at the life-cycle of bioplastics (first defining some of the important concepts associated with this life-cycle as a whole and then providing an overview of the renewable resources needed for their production) and use of different generations of bioplastics; and finally end-of-life options for these bioplastics. This is followed by a short summary of some of the more important environmental and economic issues surrounding the future development of bioplastics.

The spotlight in the next section focuses on policy options for the development of bioplastics, ranging first across the broad spectrum of instruments that could form a supportive environment for the sourcing, production and use of bioplastics and then homing in on specific instruments and options.

In turn, the actual policies and policy instruments in place in different parts of the world are presented in the next section, which looks at both national policy developments and those implemented at an international level, e.g. by the European Union (EU). These policies include both those directed specifically at the bioplastics sector and more generic policies covering other aspects of the bioeconomy that are likely to have an impact on the development and growth of the bioplastics sector.

Finally, a concluding section summarises some of the most important policy trends and key messages to emerge from this review of the policy framework surrounding the development of bioplastics.

BIOPLASTICS: FROM RAW MATERIALS TO END-OF-LIFE OPTIONS

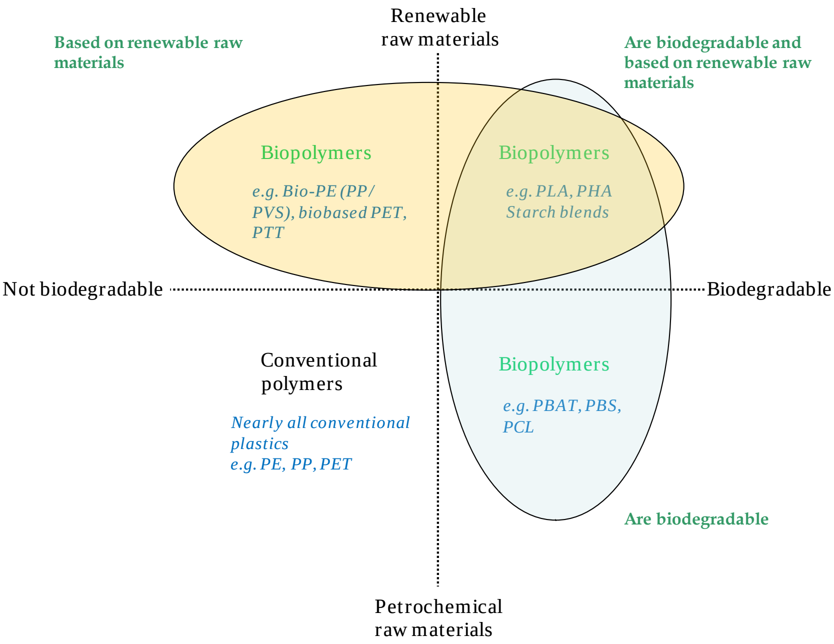
What is a bioplastic?

Before defining a bioplastics, it is necessary to define a plastic. The following description avoids overly technical language:[3]

> *"A plastic is a type of synthetic or man-made polymer; similar in many ways to natural resins found in trees and other plants. Webster's Dictionary defines polymers as: "any of various complex organic compounds produced by polymerization, capable of being moulded, extruded, cast into various shapes and films, or drawn into filaments and then used as textile fibres."*

Bioplastics, then, have similar structural and functional characteristics to plastics but are derived completely or partially from biomass resources. There is a great diversity of polymers in use or being developed as bioplastics. Interest in bioplastics has grown well beyond some of the original simple packaging applications to more sophisticated applications, including the manufacture of engineering components for extreme environments. This has required the discovery of new molecules, the blending of molecules, searches for new plasticisers and, latterly, attempts to make identical thermoplastics to the petro-plastics but using renewable raw materials of a biological origin. The result is an increasingly diverse range of bioplastics (Figure 1), by no means all of which are biodegradable or compostable.

Figure 1. Types of bioplastics, both biodegradable and non-biodegradable



Source: OECD based on European Bioplastics fact sheet - Endres and Siebert-Raths (2011).

The life cycle of a bioplastic

Given the potential for bioplastics to displace petro-plastics in some applications, with anticipated environmental benefits, this section considers the life cycle of a bioplastic, from the use of land to produce the raw materials to the final disposal options (as these have significant environmental implications for the use of a bioplastic, such as its potential for the mitigation of climate change).

The life cycle of a bioplastic includes: growth of the biomass source, harvesting of the raw material, biomass processing prior to biorefining, fermentation and downstream processing to purify the plastic, subsequent injection or blow moulding to make products, sale, use, and end-of-life options, not to mention transportation at different points in the life-cycle.

In considering this life cycle, it is beneficial to begin by defining certain terms that are used routinely: sustainability, recyclable, biodegradable and compostable.

Definitions

What is "sustainability"?

> "*There has been a growing realisation in national governments and multilateral institutions that it is impossible to separate economic development issues from environment issues; many forms of development erode the environmental resources upon which they must be based, and environmental degradation can undermine economic development*". Gro Harlem Brundtland, Oslo, 1987 - *Report of the World Commission on Environment and Development: Our Common Future"*

There are currently no comprehensive or standard definitions of sustainability, no ideal tools for measuring it, and no international agreement on the set of indicators needed to make measurements. Despite limitations, the logical starting point appears to be life cycle analyses. It seems likely that consensus could be reached on the needed measures for environmental sustainability and economic and social impacts could follow later. The concept of sustainable development has been defined rather simply as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".[4] Such a simple definition, however, lends itself to almost infinite malleability. The OECD has offered at least two definitions of sustainability, one very similar to the above. Another, in more economic terms, is "non-declining trends of economic growth and development that might be impaired by natural resource depletion and environmental degradation".[5]

Sustainability goes beyond environmental impacts to include economic and social impacts. Many companies from all sectors of industry have adopted broad sustainability goals that encompass such impacts as a result of a rise in consumer responsibility and awareness of the part they play in the attainment of sustainable ways of living. A sustainability strategy is seen by many firms as a way of gaining a market advantage over the competition. Assessing societal impacts, however, remains a considerable challenge because of the difficulty associated with identifying reliable indicators. An OECD publication (OECD 2009b) built on the National Institute of Standards and Technology (NIST) of the United States Department of Commerce BEES model for assessing overall environmental and health attributes of a product. More recently, the Global Bioenergy Partnership (GBEP) has been working on a set of measures for environmental, economic and social wellbeing (GBEP, 2011).

Concerning bioplastics, some major chemical companies are devising business models that make the business case for bioplastics whilst also addressing sustainability (Iles and Martin, 2013). This is hardly surprising as, globally, bioplastics represent the fastest growing product line in the bio-based products industry. The sustainability task for a company can be envisaged as: generating profits by making bioplastics valuable, both ecologically and socially; engaging with societal actors to define and monitor this value; and collaborating with suppliers and customers to create value for all.

What is "recyclable"?

For plastics there are two general forms of recycling:

- The reuse of the finished product after collection, cleaning and re-distribution;
- For thermoplastics (80% of the plastics market), after collection, the product can be re-melted, and remoulded, either to the same product or some other.

Recycling is a major solution to some of the environmental problems created by plastics, but it is not such a straight-forward process. Plastics require greater processing than, for example, glass and metals, and there is a need for separation according to type of plastic because different plastics tend to phase-separate when melted together, behaving rather like oil and water and setting in these layers. This causes structural weakness in the resulting material, making such plastic blends useful in only limited recycling applications. The presence of additives, such as colouring dyes, also creates recycling problems. In addition, if biodegradable plastics are mixed with petro-plastics, the reclaimed plastic may not be recyclable because of changes in properties and melt temperatures. Therefore, despite a superficial and intuitive allure, plastics recycling in reality is not simple.

What is "biodegradable"?

The OECD has explored biodegradability in detail in the past and found that there is no single definition. Rather, a range of biodegradability tests has been developed.[6] The more common tests are given below. A list of biodegradability and compostability standards is given in Annex II:

- *Ready biodegradability*: the test is conducted under aerobic conditions, in which a high concentration of the test substance is used and biodegradation is measured by non-specific parameters like CO_2 production.
- *Anaerobic biodegradability*: potential biodegradability under very low oxygen (anoxic) conditions may be examined in a screening test for anaerobic biodegradability. One importance of this is that landfill conditions are anaerobic.
- *Simulation tests*: a chemical that fails to meet the criteria for ready biodegradability, or even inherent biodegradability, may be rapidly degradable when present at low concentrations in the environment. Simulation tests are conducted to determine if this is so.
- *Ultimate biodegradability*: is the biodegradation of the test chemical or polymer to CO_2, biomass, H_2O and other inorganic substances like NH_3.

The measurement of biodegradability is therefore not the result of a single test. Test outcomes can be incorrectly interpreted or there can be insufficient information, which may result in errors, for example, in the labelling of plastic products.

The degree of biodegradation for bioplastics is also an issue. Biodegradation is often assumed to result in the total removal of a bioplastic from the environment, by mineralisation to CO_2 and H_2O, but oxo-biodegradable plastics contain metal salts that act to catalyse degradation, and this degradation can result in residual micro-fragments of plastic and metals that remain in the environment without being a visible contaminant. The impacts of small fragments of plastic produced in the degradation process on soil, water, flora and fauna are still not well characterised, but it is known that they are readily re-distributed in the environment and can easily be carried to waterways, where a range of effects is possible, including the possibility of entering food chains, and their accumulation in soil may cause ecosystem damage.

Total biodegradability and compostability cannot therefore be presumed, and in the absence of conclusive scientific evidence about the extent of biodegradability, commercial bodies are now starting to take action. For example, a large UK supermarket chain, having distributed over two billion oxo-biodegradable bags to customers, has stopped using the bags over doubts about their environmental benefits (Aylott, 2011).

What is "compostable"?

A solid material would be considered compostable when, under defined conditions in a composting system, it is entirely transformed to minerals and biomass within a specified length of time. Its decay results in a material – compost – that is a natural fertiliser that can help to restore soil fertility, control weeds, retain ground moisture and reduce soil erosion.

Among the benefits of composting the US Environmental protection Agency (EPA)[7] lists the following:

- It reduces the need for water, pesticides and chemical fertilisers;
- It serves as a marketable commodity and is a low-cost alternative to standard landfill cover and artificial soil amendments;
- It extends municipal landfill life by diverting organic materials from landfills.

To be compostable a bioplastic must:

- Biodegrade: break down into carbon dioxide, water and biomass;
- Disintegrate: after three months of composting no more than 10% residue may remain when sifted through a 2 mm sieve;
- Not be eco-toxic: i.e. the biodegradation must not produce any toxic material and the compost must be able to sustain plant growth.

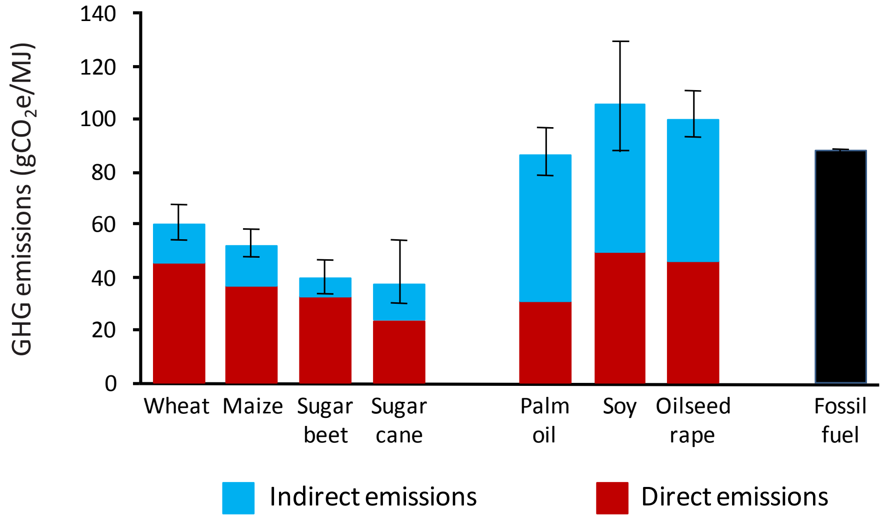
Producing the raw materials for bioplastics

Raw materials used in the manufacture of bioplastics

Whether a bioplastic is made by fermentation, or chemical polymerisation, the raw materials (monomers) are generally sugars. For example, bio-based ethylene can be produced by dehydration of ethanol, the latter being fermented from sugars. The ethylene can then be polymerised to polyethylene. A broad distinction can be made between crops from which sugars are easily extracted, such as sugar cane, sugar beet and corn, and those from which sugar extraction is technically more difficult, typically lignocellulosic crops. Examples of the latter are *Miscanthus*[8] and switchgrass,[9] both of which are grasses producing large amounts of biomass.

Care must be taken in determining the full environmental impact of using different raw materials. For example, both direct[10] and indirect[11] emissions must be determined in an impact assessment as the relative proportion of the two types of emissions varies from one raw material to another. Figure 2 illustrates this point for biofuels, which share raw material sources with bioplastics.

Figure 2. Estimated life cycle emissions from biofuels

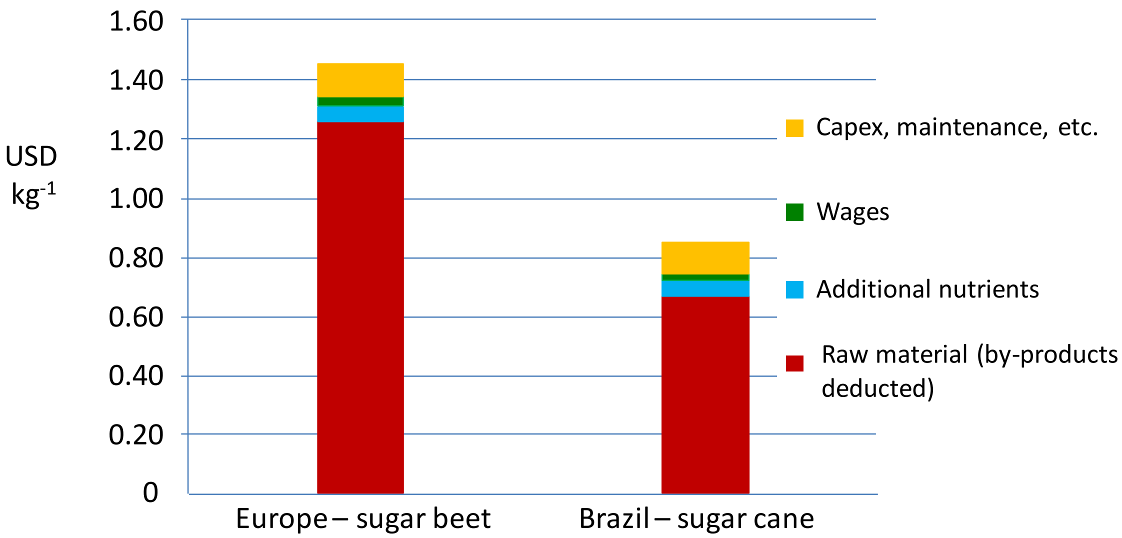


Source: OECD based on UK Bioenergy Strategy (2012).

Cost is another important factor in the use of raw materials for the manufacture of bioplastics. In Europe this has become a particular issue. Figure 3 illustrates the relative difference in cost of biorefining for sugar beet in Europe and sugar cane in Brazil, the largest proportion of the cost difference being the cost of the raw material.

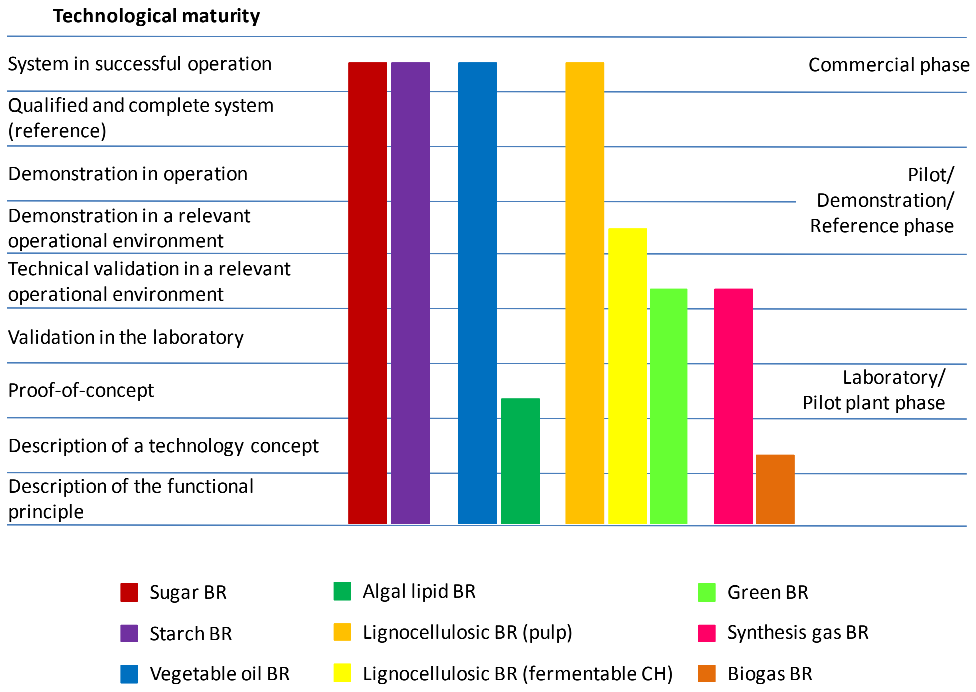
The extraction of fermentable sugars from lignocellulosic biomass still represents a challenge to the bio-based industries. Lignocellulosic biorefineries are beginning to come into operation in commercial and demonstration phases (Figure 4).

Figure 3. Relative costs in biorefinery operations for European sugar beet and Brazilian sugar cane



Source: OECD based on Delcourt (2012) at the European Forum for Industrial Biotechnology.

Figure 4. Development status of biorefinery concepts



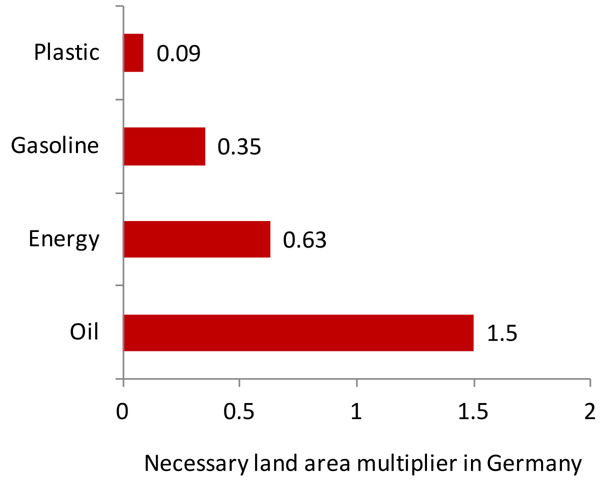
Source: OECD based on Federal Government of Germany, 2012

Land requirements for the raw materials used in the manufacture of bioplastics

Land use is a feature of standard life cycle assessments and is a staple of sustainability and biodiversity debates. The impact of biofuels on land use patterns has focused discussion on the competition for land use between biomass earmarked for the production of biofuels and plants grown only as food crops. However, biofuels have quite limited impact on land use patterns as 92% of all global arable land is used for food and animal feed production, 6% for industrial materials and only 2% for biofuels. Despite this, there has been much discussion about the impact of the use of land for biofuels on recent food price increases.

This “food *versus* fuel” discussion is also taking place around bioplastics (e.g. Zhang et al., 2010) albeit to a lesser extent than for biofuels so far. Estimates (Carus and Piotrowski, 2009) have shown that the impact of bioplastics on food markets, agricultural prices and land competition in 2008 was about 250 times less than that estimated for biofuels. The topic requires further investigation, but certainly the land requirements for bio-based energy production are much more than for the production of bioplastics. Some calculations for Germany are informative (Figure 5).

Figure 5. Proportion of land required to substitute 20% of each energy source/material with bio-based alternatives



Source: OECD based on Endres and Siebert-Raths (2011).

In addition to the significantly lower absolute quantities of land required, bioplastics exhibit higher area efficiency than biofuels. To achieve the current worldwide total production of plastics using bio-based materials would require approximately 0.01 – 0.02% of the global land area currently under cultivation.

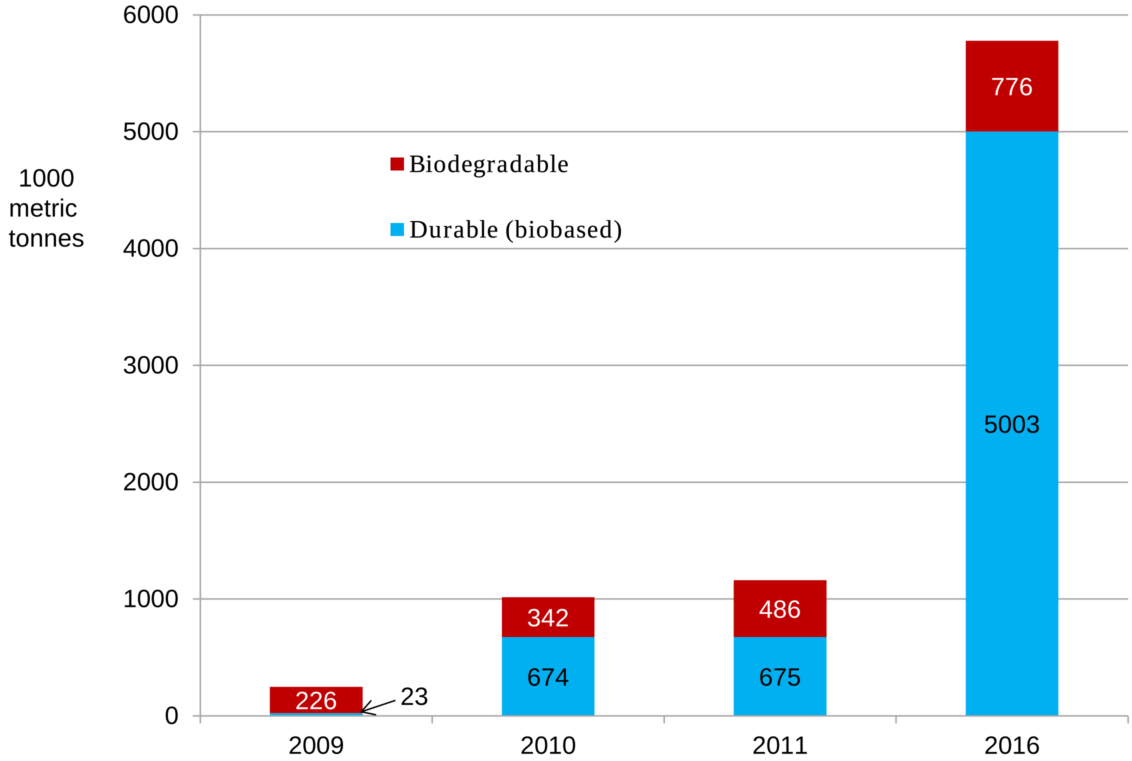
The production and use of bioplastics

Bioplastics have changed over time due to both technical developments and market demand. The development of bioplastics and their applications can be seen in terms of three generations, all of which now exist in parallel, having different characteristics. The first generation of bioplastics was characterised by a single focus on biodegradable and/or compostable plastics, primarily intended for simple packaging applications. These polyhydroxyalkanoates (PHAs), which entered industrial scale production in the 1980s and 1990s, are formed by direct fermentation and are biodegradable. They have struggled to compete on cost and performance with the petrochemical thermoplastics that dominate the market. However, it is likely that all types of bioplastics will survive in some applications as they have found a niche, making them difficult to be displaced by other materials.

The second generation was an improvement on the first in terms of performance. They have better processing and performance characteristics, and they are increasingly competitive in certain applications, especially packaging. Indeed, these second generation materials were specifically developed to be biodegradable and compostable for the packaging, agricultural or gardening sectors. Second generation bioplastics have reached industrial scale production but are still at a price disadvantage relative to petro-plastics. Some have recently started to diffuse into other application areas, e.g. engineering applications, and other sectors, notably the automotive (e.g. JCN Newswire, 2010) and consumer electronics sectors (e.g. Ravenstijn, 2010)

Third generation bioplastics are far more durable, a move from degradability towards resilience. They are generally bio-based equivalents of the major thermoplastics that dominate the market – polyethylene (PE), polypropylene (PP) and polyethylene terephthalate (PET) – with bio-based equivalents of polyvinyl chloride (PVC) expected to be in production by 2015 – although it is only recently that bio-based equivalents of PE and PP have been viewed as realistic competitors to the major thermoplastics. Bio-PE and bio-PP are not directly fermented; they are produced chemically from monomers which are produced by fermentation. Their lack of biodegradability is not an issue as they have identical performance characteristics to the petro-based equivalents and, importantly, can directly enter existing recycling systems. They can be categorised as bioplastics as their carbon content comes from renewable resources, and they therefore have a potential contribution to make to greenhouse gas (GHG) emissions savings. It has been predicted that the global trend in bioplastics production will shift significantly to be dominated by durable bio-based thermoplastics (Figure 6), such as bio-PE, bio-PP, bio-PET and, potentially, bio-PVC.

Figure 6. Predicted global production capacity of bioplastics



Source: OECD based on European Bioplastics. (http://en.european-bioplastics.org/market/market-development/production-capacity/).

However, a recent update, from the industry organisation European Bioplastics[12] is significant. The market of around 1.2 million tonnes in 2011 may see a five-fold increase in production volumes by 2016, to almost 6 million tonnes. The product expected to contribute most to this growth is bio-based PET (for plastic bottles), which already accounts for approximately 40% of the global bioplastics production capacity. The current production volume is expected to grow to more than 4.6 million tonnes by 2016 as a result of demand from large manufacturers of carbonated drinks. Early in 2013 the nova-Institute predicted that by 2020 bioplastics production could rise to 12 million tonnes, principally due to drop-in polymers, particularly bio-PET[13]. With an expected total polymer production of about 400 million tonnes in 2020, the bio-based share should increase from 1.5% in 2011 to 3% in 2020.

In terms of next generation developments, the techniques of synthetic biology are already being applied to bioplastics production, at least in the laboratory. This development may make industrial scale production more controllable, more scalable and more cost-effective. In addition, research is looking at the production of bioplastics in plants as well as through fermentation processes.

The main plastics made directly by fermentation are the PHAs. Research has been directed towards modifying the structure of PHAs to make bioplastics with improved performance with the aim of matching the well-researched and developed high performance of petro-plastics. The earliest work on PHA was its production from *Cupriavidus necator* (formerly *Ralstonia eutropha* and before that *Alcaligenes eutrophus*). In comparison with *R. eutropha*, recombinant *E. coli* has several advantages: fast growth; a large amount of polymer accumulation; the ability to use various substrates; well-established high cell density culture techniques; a lack of PHA depolymerases; and improved size profile and crystallinity (PHA granules synthesised by recombinant *E. coli* are larger and more crystalline than those produced by *R. Eutropha*) (Yim et al., 1996). In addition, regulators are familiar with *E. coli*, a further advantage.

Much has been done on metabolic engineering of better production strains producing greater variety of types of PHAs, warranting a major review as early as 1999 (Madison and Huisman, 1999). Metabolic engineering, combined with the techniques of minimal genomes (the minimum number of genes required to support basic life) (Mushegian, 1999), is now part of the current industrial toolkit of synthetic biology.

Polylactic acid (PLA) is a biomass-derived thermoplastic with proven GHG emissions savings that is a strong candidate as a substitute for some petro-plastics. The current commercial PLA products are not made by direct fermentation but are synthesised by ring opening polymerisation (ROP) of lactide, a cyclic dimer of lactate (Vink et al., 2004). Its monomers can therefore be fermentation-derived (even though the polymer is chemically synthesised), thereby qualifying PLA as a bio-based plastic.

Recently the metabolic pathways of *E. coli* were engineered to achieve efficient production of PLA and lactate-containing copolymers by direct fermentation without the need for a complex chemical process (Jung and Lee, 2011). This removes concerns that the chemical process can be compromised in human and food applications by traces of heavy metal catalysts that remain after polymerisation. The development of an efficient process for the production of PLA by engineered PHA biosynthesis systems may have a significant commercial impact, since fermentative PLA synthesis has several advantages that possibly solve the problems encountered during chemical synthesis of PLA using lactides. This is a route to the production of unnatural, tailor-made polyesters via synthetic biology. It can be expected that such production strategies will be repeated many times over in future, for bioplastics production and many other applications, such as pharmaceuticals and fine chemicals.

Another avenue of research is the production of bioplastics in plants rather than by fermentation from microorganisms. Under conditions of high yield, life cycle assessment (LCA) has suggested that the production of biopolymers in plants may offer superior GHG emissions savings to fermentation processes (Kurdikar et al., 2001). The direct synthesis of biopolymers in plants is also theoretically more energy efficient and requires fewer steps (van Beilen and Poirier, 2012). However, in terms of product yields and process control, fermentation is more efficient than production in plants. There is also the major constraint of seasonal harvesting but Somleva et al. (2008) demonstrated that production of polyhydroxybutyrate (PHB) in switchgrass can be made more cost-effective than it is currently. This non-food crop has proven to be amenable to the complex metabolic engineering necessary for production of high-value biomaterials with lignocellulose-derived biofuels as a co-product.

No matter what the future of bioplastic manufacture will be, recycling and disposal will be important for all generations of bioplastics. The next section considers these and other end-of-life options for bioplastics.

End-of-life options for bioplastics

> "*Although PLA has enormous potential to succeed in the US market as an alternative to traditional plastics, the end-of-life dilemma remains a looming obstacle that will need to be addressed before its true cradle-to-cradle nature can be realised*". Wedewer, 2011

End-of-life options are major considerations for bioplastics. The true environmental impact of a material is not assessed in a “cradle-to-factory gate” life cycle assessment (LCA), as this ignores the energy, economic and environmental implications of final disposal (Hermann et al., 2011), but rather “cradle-to-grave”. In the case of plastics, many of which are produced with the intention of a single use, this is a critical factor. Cradle-to-grave LCA is likely to reveal quite different results. Irrespective of the end-of-life option, the plastics also have to be collected and transported to the appropriate facility, requiring extra energy input and other inputs associated with transportation.

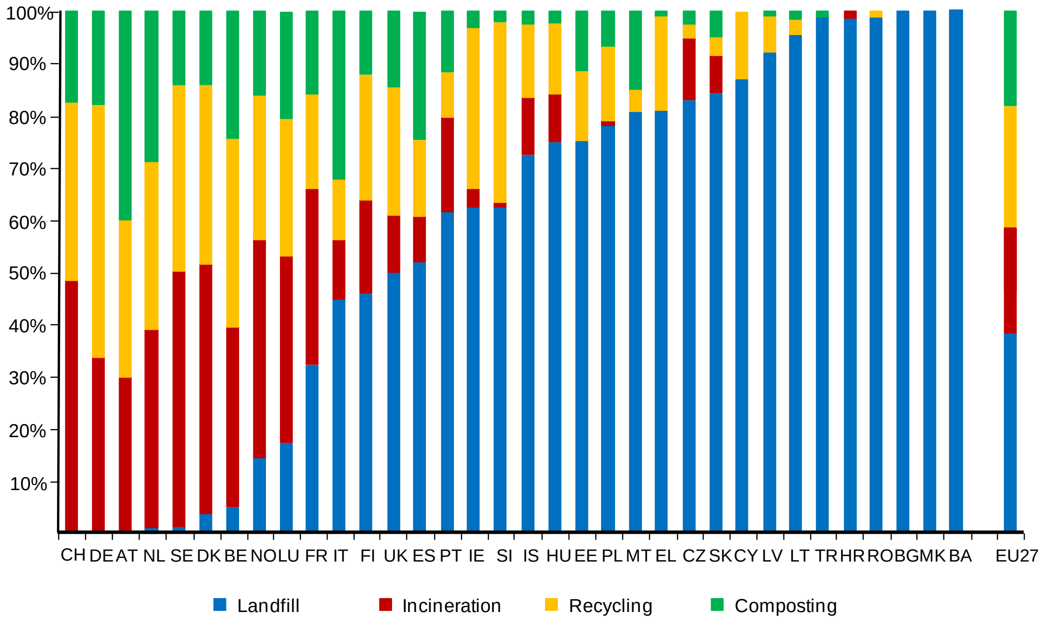
There are various end-of-life options depending on the type of plastic:

- Composting (aerobic and anaerobic);
- Recycling;
- Monomer recovery;
- Incineration (with or without energy recovery).

End-of-life impacts are highly dependent on local infrastructure. Evaluation of the societal benefits or burdens of each end-of-life option requires data on the inputs and outputs of each process. Gathering the data for these inputs and outputs can be technically, and sometimes politically, challenging. A wide variety of actual disposal regimes exists globally, as exemplified by the situation in the European Union (Figure 7), where the use of landfill as the method of disposal of municipal solid waste varies from 0% (in three of the 27 EU countries) to 100 % (in three other European Union countries).

Furthermore, a bioplastic may not qualify for a particular end-of-life option. One potential large-scale application for biodegradable plastics is food packaging, which might appear ideally suited to disposal by recycling, followed by biodegradation. However, a typical recycling facility is not equipped to deal with food-contaminated packaging and so currently most of this material is disposed of in landfills.

Figure 7. Municipal waste treatment, Europe 2009



Source: OECD based on Eurostat (2011). Municipal waste statistics. The percentage on the x-axis refers to the amounts of municipal waste land-filled, incinerated, recycled and composted as a percentage of the total amounts treated.
http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Municipal_waste_statistics

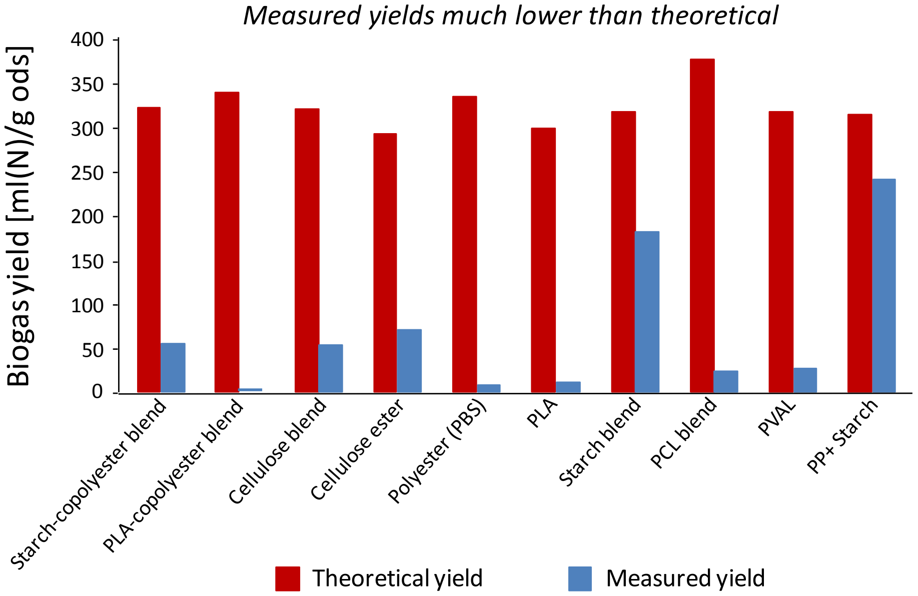
Composting (aerobic and anaerobic)

Despite an apparent allure, composting as a solid waste treatment option has been used very little. The problems associated with poor quality compost, containing, for example, high levels of heavy metals and other contaminants such as glass, have been known for decades (e.g. De Wilde and Boelens, 1998). More recently, source-separated waste collection has been introduced in many countries. Landfill costs have been driven up, allowing composting to become more cost-competitive. Many countries have banned the land-filling of putrescible[14] waste.

Aerobic composting results in the production of foul air which should be prevented from migrating off-site. The development of in-vessel composting can control odours, whilst also offering much improved process control. Composting on a large scale requires separation, collection and transport to an industrial composting facility, which incurs considerable expense and may leave it at a disadvantage with respect to some other end-of-life options. For example, the amount of CO_2 generated by composting equals the amount of CO_2 released by incineration but the latter can be more attractive if heat is recovered and power is generated during the incineration.

Bioplastics have a high molecular weight that would theoretically make them good candidates for anaerobic biological treatment. The theoretical yields of biogas are encouraging, but there is little information based on practical experience. Figure 8 shows a large difference between theoretical and laboratory practical yields of biogas from various bioplastics. The measured yields are, generally, much lower than expected.

Figure 8. Biogas yields from various biopolymers



Source: OECD based on Endres & Siebert-Raths (2011).

A recent study detected no direct biological degradation of a commercially available PLA under anaerobic conditions (Kolstad et al., 2012). Perhaps any degradation of PLA in a landfill would require a chemical hydrolysis step prior to any biodegradation, which is analogous to the situation in aerobic composting. At 20°C, this process is estimated to take over 100 years and, under those conditions, the degradation of the PLA would be extremely low. The desired situation is to have a bioplastic that can be aerobically composted but which will not cause methane emissions if disposed of in landfill.

Recycling

At present, thermo-mechanical recycling of bioplastics is highly disfavoured as it faces the same challenges as recycling of petro-plastics. Down-cycling (conversion into materials of lesser quality and reduced functionality) due to depolymerisation during thermal load, exacerbated by hydrolysis in the presence of moisture, is likely to be even more problematic for biopolymers than petro-plastics due to their generally inferior thermo-mechanical properties.

Conventional petro-plastics recycling facilities greatly favour the inclusion of only single types of plastic in a waste stream, necessitating sorting, which is difficult and expensive. This is also true of bioplastics, where significant loss of quality in the recyclate can be expected. The presence of PLA bottles in PET recycling streams has already caused controversy due to the mixing of polymer types (Verespej, 2009). However, trials are underway with near infra-red (NIR) detection systems that can be used to detect bioplastics. When sufficient product and recovery volumes of bioplastics have been achieved, mono-material mechanical recycling has the potential to be a viable, sustainable end-of-life option.

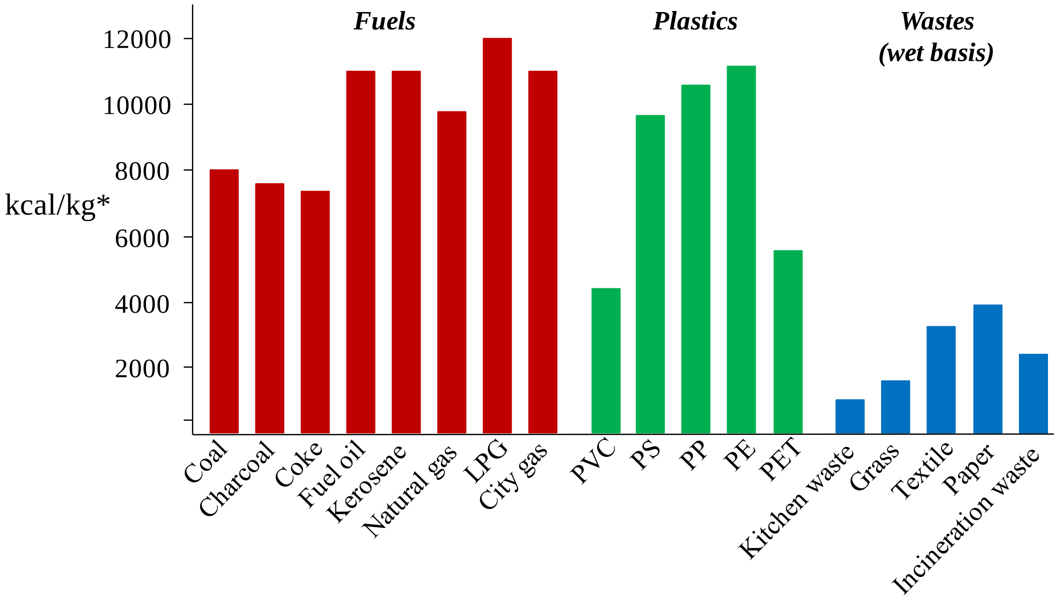
Monomer recovery

Chemical recycling of PLA back to the monomer lactic acid is also possible. Sorted PLA waste can be cleaned, shredded and hydrolysed back to lactic acid at around 99% efficiency (European Bioplastics, 2010). Again, sufficient industrial and consumer PLA waste streams will need to be generated for hydrolysis plants to be economically viable.

Incineration with or without energy recovery

Petro-plastics are useful fuels due to their high density of calories per unit volume (Figure 9). Generally petro-plastics have higher calorie values (of the order of 25 GJ per tonne) than bioplastics (of the order of 10 GJ per tonne) except for the bio-based equivalents of conventional plastics, which are identical in calorie values as they are identical molecules.

Figure 9. Calorie values of plastics, fuels and wastes (*(kcal per Nm^3 for natural gas and city gas)



Source: OECD based on Ida (2008) (www2.pwmi.or.jp/ei/index.htm)

In general, incineration of plastic wastes results in a volume reduction of 90–99%, thereby greatly reducing the amount of landfill required to dispose of the waste. The effectiveness of incineration is reduced in the presence of food and other wastes having high moisture content.

In countries that have a well-developed infrastructure for incineration with energy recovery, this is an attractive end-of-life option for bio-based plastics. Incineration with energy recovery is suitable for all bioplastics and their composites, irrespective of the raw materials used in their production or their biodegradability and compostability. In Japan, for example, 15 MT of plastics are produced annually and 10 MT of plastics are discarded. Roughly half of the discarded materials are incinerated, and incineration is mostly accompanied by heat recycling and power generation.

Environmental and economic issues surrounding bioplastics

This section considers the potential impact of the increased manufacture and application of bioplastics on different aspects of the environment (e.g. climate change and GHG emissions, the ocean accumulation of petro-plastics, the disposal of solid waste etc.), and on the economy (e.g. on energy resources and employment).

Environmental issues

The attractiveness of bioplastics as replacements for petro-based plastics is dependent in part on their ability to meet environmental as well as economic goals. Bioplastics, as well as other bio-based products, are of high societal, environmental and economic interest due to:

- Their use of renewable resources, resulting in the lower dependency of plastics on increasingly expensive fossil resources;
- Their potential ability to reduce GHG emissions throughout their lifecycle, compared with petro-plastics, and the potential for more sustainable industrial production of plastics (e.g. by reducing GHG emissions);
- Their potential to offer better recovery and recycling options than petro-plastics and other materials, including often high biodegradability or compostability;
- Their scope to enhance industrial competitiveness through new innovative eco-efficient bio-based products and applications; and
- The higher job creation potential of bio-based products compared with that for biofuels.

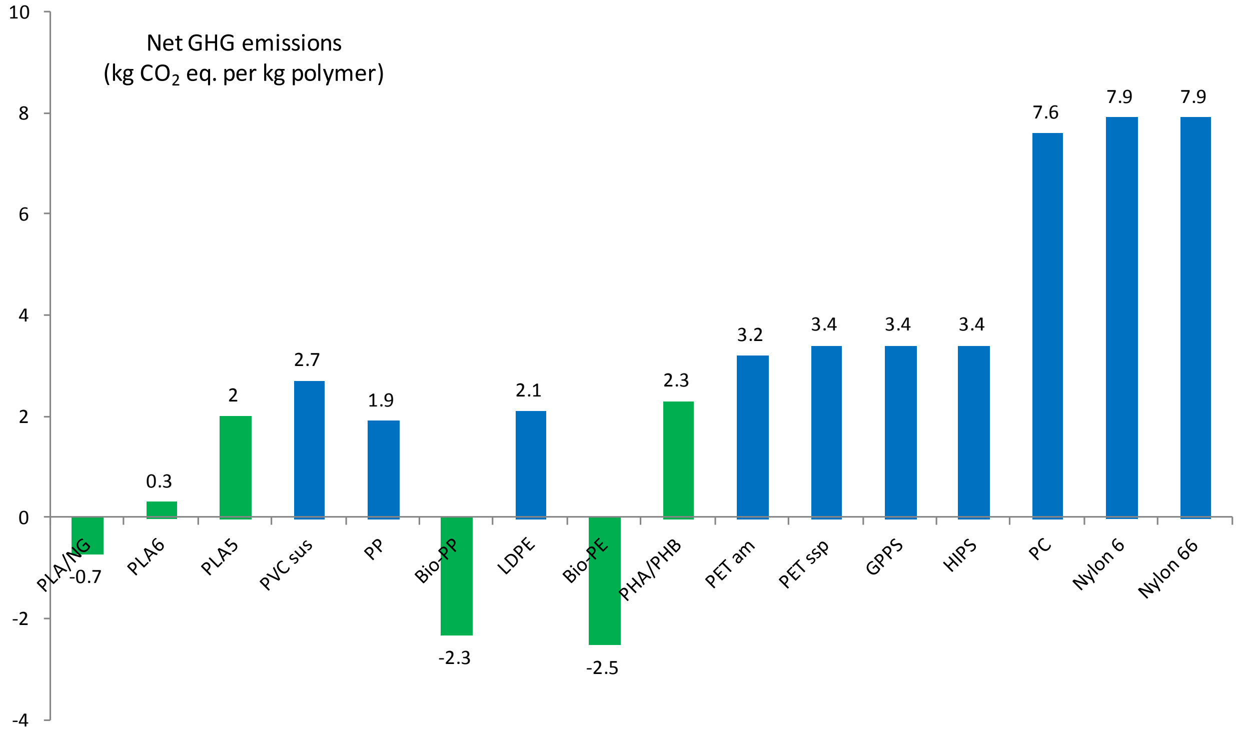
Climate change and GHG emissions

An important aspect of plastics manufacture is GHG generation and its impact on climate change. The projections of the Intergovernmental Panel on Climate Change (IPCC) for stabilisation of atmospheric GHG concentrations at 450 ppm CO_2 by 2050 require reductions in emissions of 80% compared to the 1990 level (Barker et al., 2007), a huge challenge for all sectors of the economy. Several countries have adopted targets for such large reductions in GHG emissions (Williams et al., 2012), and the development of a national strategy for a bio-based economy is a firm policy objective for many countries.

Figure 10 shows a range of cradle-to-factory gate estimates for the GHG emissions associated with various fossil-based and bio-based polymers. In general, the emissions tend to be higher for the fossil-based polymers, while those associated with bio-based polymers have negative as well as smaller positive values. It should be remembered, however, that these are not cradle-to-grave estimates, and as such they exclude the impacts associated with use, recycling and disposal.

A comparison of the cradle-to-grave GHG emissions associated with conventional and bio-based chemicals, based on a total of 44 LCA studies covering approximately 60 individual bio-based materials and 350 different life cycle scenarios (Weiss et al., 2012), suggests that the GHG emissions savings associated with bio-based products (including bio-based plastics such as polytrimethylene terephthalate, polylactic acid and PHA) are superior to those for their conventional counterparts (Figure 11). However, the error margins associated with these estimates are considerable, and statements about the beneficial impacts of bioplastics regarding GHG emissions are tentative. They are also likely to remain cautious in the absence of an international accord on the best ways of conducting LCA studies. LCA methodology has been standardised under the ISO-14040 series distinguishing four key phases (goal and scope definition, inventory analysis, impact assessment, and interpretation), but despite the existence of these standards, the number of degrees of freedom for conducting LCAs remains significant.

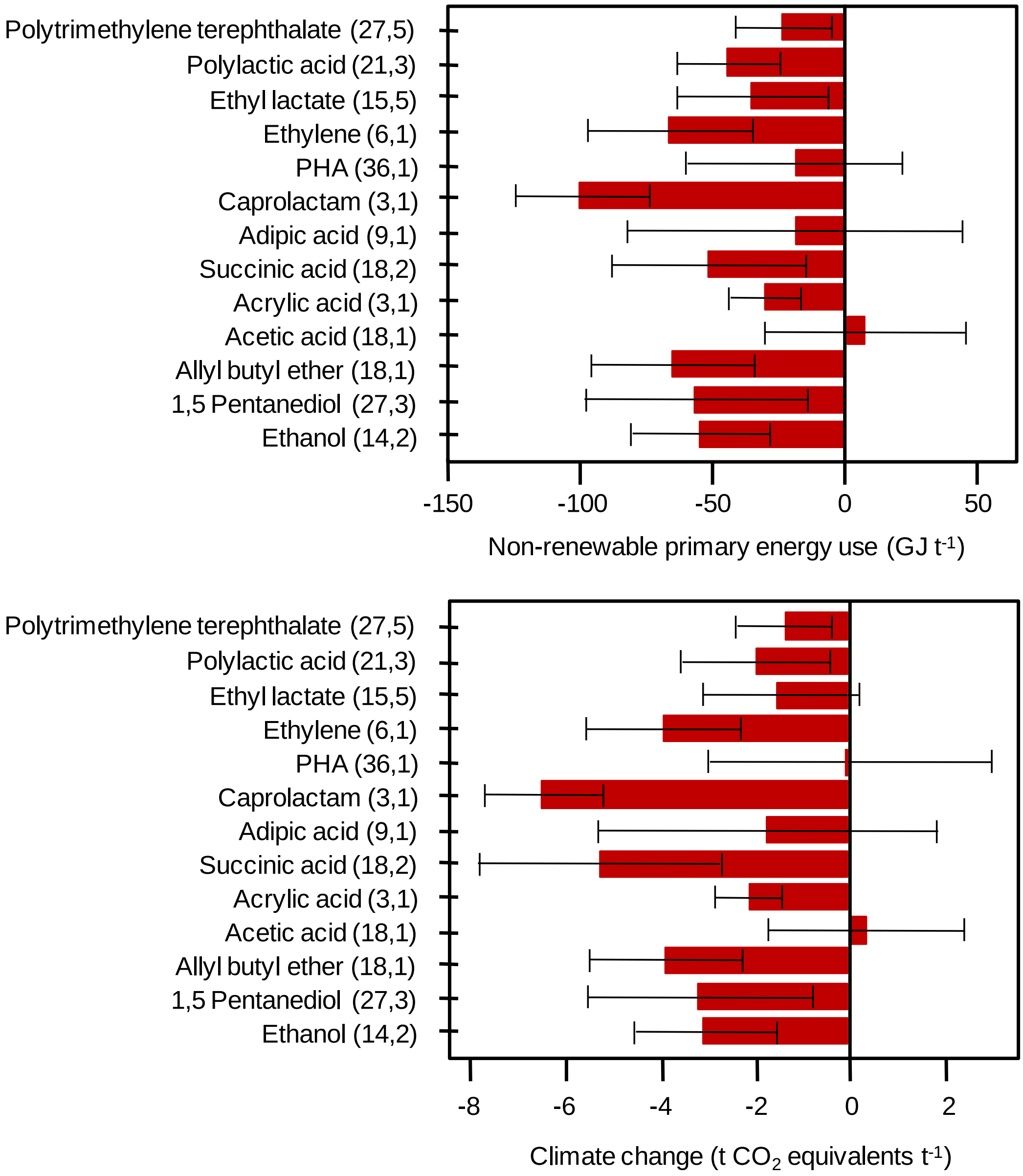
Figure 10. Greenhouse gas emissions (as CO_2) for various petro- and biopolymers



Note: PLA/NG = NatureWorks® PLA next generation, PLA5 = NatureWorks® PLA in 2005, PLA6 = NatureWorks® in 2006, PVC sus = PVC suspension, HIPS = high impact poly(styrene), PC = poly(carbonate), GPPS = general purpose poly(styrene), PET am = PET amorph, PET ssp = PET solid state polycondensed, Bio-PP = Braskem bio-based polypropylene, Bio-PE = Braskem bio-based polyethylene.

Source: OECD based on various: Jamshidian et al., 2010; Smith, 2010; Tullo, 2010; Gerngross, 1999; Harding et al*.,* 2007; and Kurdikar et al*.,* 2001). The green bars indicate biopolymers; the blue petro-based polymers.

Figure 11. Average non-renewable primary energy use and GHG emissions of bio-based chemicals in comparison to conventional chemicals



Source: OECD based on Weiss et al. (2012). Numbers in parentheses indicate the sample size for the bio-based and conventional chemicals, respectively.

Ocean accumulation of petro-plastics

The problem of pollution by plastics that do not biodegrade becomes apparent when noting that 75–80 million tonnes of packaging plastics are used globally per annum and that plastics accumulate in the environment at a rate of 25 million tonnes per annum (Ojeda et al., 2009a; Sudhakar et al., 2008), much of which ends up in the oceans. Once in the oceans, the rate of biodegradation is exceptionally slow. There are also virtually no data on kinetics of mineralisation of plastics in the marine environment.

There has been a growing awareness of the accumulation of large quantities of plastic wastes in certain ocean locations e.g. the North Atlantic Gyre (Law et al., 2010), and the Northern Pacific Gyre's ''eastern garbage patch" (Rios et al., 2010). In a long-term study in the North Atlantic, the largest sample collected in a single 30-minute tow was 1069 plastic pieces at 24.6°N, 74.0°W in May 1997. This is equivalent to 580 000 pieces per square kilometre (Law et al., 2010).

Whilst ocean waters generally contain very low concentrations of pollutants, persistent bioaccumulating and toxic contaminants can become concentrated when they adsorb to drifting plastic waste. Of particular concern is the accumulation on such plastics of polychlorinated biphenyls (PCBs), chlorinated pesticides, and polycyclic aromatic hydrocarbons (PAHs), which are known carcinogens, and are considered to be endocrine disrupting chemicals (EDCs). In a study by Teuten et al. (2007), equilibrium distribution coefficients for sorption of phenanthrene from seawater onto plastics were shown to vary widely, but in the cases of polyethylene (PE), polypropylene (PP) and polyvinyl chloride (PVC) sorption to plastics greatly exceeded sorption to two natural sediments (Table 1).[15] This demonstrates in the laboratory the predisposition for hazardous, toxic pollutants to accumulate on plastics in the marine environment.

Table 1. Recovery of phenanthrene in each phase in sorption experiments

	Total PHE recovered in each phase (%)			
	Liquid	**Glass wall**	**Solid**	**Total (%)**
	In seawater:			
Polyethylene	4.6 ± 0.5	0.6 ± 0.3	80.5 ± 6.4	85.7 ± 6.5
Polypropylene	37.4 ± 0.7	1.2 ± 0.4	35.6 ± 0.9	74.1 ± 1.2
$PVC_{200\text{-}250}$	67.6 ± 8.6	1.3 ± 0.2	27.3 ± 3.8	96.3 ± 4.8
Plym sediment	73.8 ± 2.0	2.4 ± 1.1	3.3 ± 0.5	79.5 ± 2.2
Mothecombe sediment	88.1 ± 3.9	2.0 ± 0.4	0.4 ± 0.1	90.5 ± 4.5

Source: OECD based on Teuten et al*,* 2007

Bioplastics that are fully biodegradable do not pose the same problems as non-biodegradable conventional plastics. However, a relatively recent realisation is that "microplastics", which can result from the partial degradation of bioplastics, are accumulating in the environment, especially in marine environments (GESAMP, 2010). Microplastics have large surface to volume ratios, potentially facilitating contaminant exchange, and have been shown to be ingested by a range of organisms. One of the greatest uncertainties is whether this leads to the bioaccumulation of the contaminant load (absorbed and plastic additives), and hence whether microplastics represent an additional and significant vector for transferring pollutants and toxic substances.

Disposal of solid waste

The expanding human population, with its throw-away philosophy, has led to a very rapid development in the global consumption of plastics. Non-degradable and other plastics can be disposed of in landfill sites, a major disposal route for plastics. While less widely recognised as a global challenge, disposal of solid waste is becoming increasingly difficult, largely because sites suitable for development for landfill are becoming rarer in many diverse countries, as these examples show:

- In Japan, where there is limited space and high population density, it is becoming increasingly difficult to obtain public acceptance to install waste disposal facilities, such as landfill sites, due to growing public concern over environmental and health protection (Ishizaka and Tanaka, 2003).

- Singapore has a single landfill site, situated 25 km offshore, which is due to be filled by 2030 (Khoo and Tan, 2010). Increasing costs and dwindling supply of landfills are forcing consideration of alternative options for the disposal of plastic wastes (Zia et al., 2007).

- In Australia, with its large land mass and low population, it is considered that the available supply of landfill is a scarce resource that should be used conservatively (Pickin, 2009).

- During the 1980s, solid waste disposal emerged as a potential crisis in many areas of the United States due to increasing amounts of municipal solid waste (MSW), shrinking landfill capacity, rising costs, and strong public opposition to new solid waste facility sites (Regan et al., 1990). In 2010, plastics were 12.4% of US MSW in comparison to less than 1% of United States MSW in 1960 (US EPA, 2011), with only 8.2% of total plastics waste being recovered in 2010.

This problem of solid waste disposal has become a global issue. After food waste and paper waste, plastic waste is the third major constituent of municipal and industrial waste in cities (UNEP, 2009). For example, the current MSW of Singapore is 12% plastic. Legislation has been developed in many countries with the aim of maximising the efficiency of use of landfill sites, by diverting materials to other end-of-life options.

While the durability of plastics in simple, single-use packaging functions can be a benefit in some respects, it is also of concern. For example, expanded polystyrene foam is widely used as protective packaging for electronic goods. It is low weight and high volume and does not biodegrade. Disposing of it in landfill is a wasteful use of a limited resource, particularly as the waste will remain intact in the long-term.

One option is to make greater efforts to ensure that as many durable plastics as possible enter conventional recycling schemes. Another is to replace such durable plastic materials with compostable bioplastics. These offer not only the promise of a reduction in landfill volume but they also make the collection of food waste for composting or anaerobic digestion easier, leading to substantial reductions in uncontrolled methane generation and reducing the need for landfill.

In a cradle-to-grave study on the environmental impacts of conventional and bio-based carrier bags in Singapore (Khoo and Tan, 2010), the most severe end-of-life environmental impacts were associated with the dumping of carrier bags in landfills. In the case of these and other light plastic materials, a further problem occurs when they become wind-blown, creating litter and a potential hazard to the environment (including wildlife around and outside the landfill site).

It is clear that plastics are a material of choice for an increasing number of applications, as is reflected in increasing production volumes. It is also clear that fossil-derived plastics contribute to a range of environmental concerns relating to their production and disposal. Bio-based plastics, whether biodegradable or durable, can play a role in mitigating some of these problems. The truly compostable plastics could be diverted from landfill operations and could also contribute a new and valuable material from their degradation – compost. The durable bio-based thermoplastics are able to enter the recycling streams of the fossil-derived thermoplastics of identical composition.

Economic issues

In a future bioeconomy, a substantial proportion of fossil-based plastics may be substituted with bioplastics, although the actual percentage is disputed. One study (Shen et al., 2009) stated that the total *technical* maximum substitution potential for bioplastics to replace their petrochemical counterparts was estimated to be 90% of total polymer consumption (including fibres) as of 2007. On the other hand, the United States Department of Agriculture (USDA) has estimated the upper limit for substitution to be 33%. Whatever the exact figure, substitution of this scale is likely to have a number of potential economic impacts, including impacts on the demand for oil and other fossil fuels and implications for employment levels. Potential stimuli and barriers to the growth of a bioplastics sector also have to be considered.

Reducing oil dependence

Plastics are ubiquitous and popular materials, and there is no reason to expect the demand for plastics to diminish in the medium term. Indeed, it is likely to increase substantially. In turn, an expansion of demand for plastics would increase the demand for crude oil if plastics remain largely oil-based. Crude oil consumption has been growing at a rate of approximately 2% per annum in recent years, but there is increasing competition for its use and mounting evidence that crude oil is becoming increasingly difficult to find. In the absence of significant new finds in easily accessible locations, any expansion in consumption will become unsustainable. Crude oil can be expected to become more expensive and its supply more volatile, with many independent institutions and publications supporting the contention that conventional oil production may soon go into decline (Owen et al., 2010).

The cost of traditional plastics is directly linked to crude oil prices, being both the raw material and an energy source for plastics production. Long-term plastics prices, like those of crude oil, have continuously increased. The doubling of plastics production volume in the last 15 years, the volatility of crude oil prices and the increasing difficulties of finding new sources of oil have all raised concerns about the sustainability of the rapid growth in oil-based plastic production.

In Asia, coal rather than oil is increasingly used as a polymer raw material (Khoo et al., 2010), but this has led to concerns about the potential impact on the climate, especially compared to the use of renewable sources to produce bioplastics.

There is a need to find alternative feedstocks for plastics unless breakthroughs in alternative transport fuels and power generation arise that can divert crude oil from these purposes. Many of the world's economies are overly dependent on fossil fuels. The European Union, for example, is far from alone in being vulnerable to insecure and dwindling oil supplies and market volatility. To remain competitive, the EU needs to become a low carbon society in which resource efficient industries, bio-based products and bioenergy all contribute to green growth and competitiveness (European Commission, 2012a).

Creating jobs

Estimates of job creation associated with "green growth" or the "bioeconomy" vary considerably from one location to another, primarily because there are no universally accepted definitions of these concepts, but the estimates that do exist are generally positive. One recent study of green jobs in the United States, for example, estimated that green jobs would increase from a base of 750 000 in 2006 to 3.3 million green jobs by 2018 (Peters et al., 2010).

In "*Innovating for Sustainable Growth: a Bioeconomy for Europe*", the European Commission (2012a) stated that the European Union's bioeconomy sectors were worth EUR 2 trillion in annual turnover and accounted for more than 22 million jobs and approximately 9% of the workforce. The *Europe 2020 Strategy*, which contains two flagship initiatives of great relevance to job creation within the bioeconomy

(*Innovation Union* and *A Resource Efficient Europe*), envisages the development of the bioeconomy as a crucial component of smart and green growth in Europe. Moreover, the European Commission estimates that the direct research funding associated with the Bioeconomy Strategy in its *Horizon 2020* initiative could alone generate about 130 000 jobs and EUR 45 billion in value added across all bioeconomy sectors by 2025, including bioplastics.

A recently published Spanish study entitled "*Green jobs for sustainable development. A case study of Spain*" (Sustainlabour, 2012) has quantified between 400 000 and 500 000 green jobs in Spain, equivalent to 2.2% total employment in Spain. This was carried out with the co-funding of Sustainlabour,[16] and in collaboration with the Biodiversity Foundation (Ministry of Agriculture, Food and Environment) and the OIT (International Work Organisation). The contribution of green economy to the total Spanish economy has been estimated in EUR 25 billion annually, equivalent to 2.4% total GDP.

Table 2 contains an estimate of bioeconomy jobs in the Flanders region of Belgium (Vandermeulen et al., 2011). In the bioeconomy of this region, bioplastics are more important than the production of bio-based fuels, although both are dwarfed by the jobs generated by bio-based chemicals.

Table 2. The Flemish bioeconomy

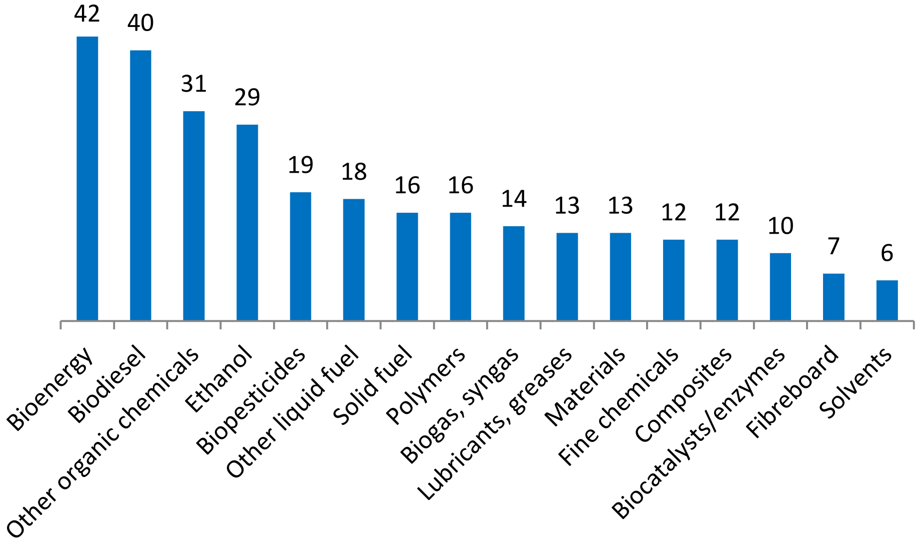
	Gross margin		Employment	
	M EUR	**%**	**FTE**	**%**
Bio-based energy				
Bio-based gas	38	3.3	374	4.0
Bio-based electricity	89	8.0	456	4.9
Bio-based heat	210	18.8	842	9.0
Bio-based fuels	25	2.2	146	1.6
Sum	***362***	***29.4***	***1818***	***15.4***
Bio-based products				
Paper	215	19.3	1546	16.5
Fibreboards	256	22.9	1991	21.3
Bioplastics	52	4.7	847	9.1
Bio-based chemicals	268	24.0	3532	37.7
Sum	***791***	***70.9***	***7916***	***84.6***
Total bio-based economy	1153	100	9361	100
Total Flemish economy	60 949		2 585 296	
Bio-based % of economy	1.8		0.4	

Source: OECD based on Vandermeulen et al. (2011). FTE = Full-time labour equivalents

Subsequent to this study, Flanders published a bioeconomy report (Sormann, 2012). This confirmed that, in Flanders, bio-based products (such as paper, wood-fibre boards, bioplastics and biochemicals) create five times more added value (based on gross margin calculations) and ten times more employment than bioenergy (i.e. bio-based electricity or heat and biofuels). Similarly, Carus et al. (2011) note that the production and use of bio-based products can directly support 5 to 10 times more employment and 4 to 9 times the value-added compared to the production and use of bio-based energy, principally due to longer, more complex supply chains associated with the production of bio-based products.

Despite the higher job creation potential of bio-based products over the production of biofuels, in many countries there is a marked preponderance of firms dedicated to the latter. In 2009, for example, the number of companies in the Canadian bio-based industries producing biofuels (i.e. energy, diesel, and other fuels) was significantly higher than the number producing bioplastics (i.e. polymers) (Figure 12). Sparling et al. (2011) have speculated that supportive policies for biofuels have enabled the growth of some businesses, with growth being based on a combination of private investment and government grants and loans. Such measures, however, have not been available for the bioplastics industry.

Figure 12. Number of firms in Canada by bioproduct type in 2009



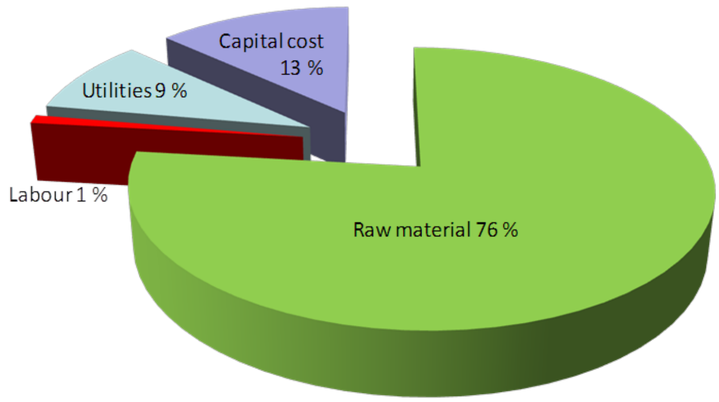
Source: OECD based on Sparling et al*.* (2011).

The cost of manufacturing bioplastics

One primary barrier to the growth of the bioplastics sector is that bio-based plastics remain more expensive to produce than their petro-equivalents, leading to higher market prices. For example, PHA plastics in the form of pellets were still being sold in 2009 at three times the price of polypropylene (DiGregorio, 2009).

The costs associated with raw materials dominate production costs. An analysis of the costs of a mid-sized polylactic acid (PLA) production plant by Uhde Inventa-Fischer, for example, demonstrate this vividly (Figure 13).

Figure 13. Cost split for a mid-sized PLA plant



Source: OECD based on Uhde Inventa-Fischer-publicly available commercial documents

One of the most significant challenges is to reduce the costs associated with the need for large quantities of glycoside hydrolase (GH) enzymes to convert lignocellulose efficiently into fermentable sugars. These enzymes are typically generated in an expensive dedicated process that makes the second highest contribution to raw material costs after the feedstock itself (Blanch et al., 2010).

As of 2011, prices for bioplastics ranged from EUR 1.5 per kg (PLA) to EUR 15 per kg (for a specific PHB), although for bulk bioplastics the range was EUR 3-6 per kg. These prices shift constantly as they depend not only on the volume required but also the volume of bioplastics produced, but it is safe to assume that the price of PLA will continue to decrease as new manufacturing capacity is added. Some bio-polyesters and PHA are currently available at a price starting around EUR 3 per kg and they will also continue to decrease in price as long as increased demand and market penetration lead to economies of scale. Additional manufacturing capacity is being planned for PHA by several companies (for example, BioMatera, Meridian, and Tianjin Green BioScience), which gives substance to this assumption.

Although there is currently a price differential between petro- and bioplastics, in recent years the prices of bioplastics have been dropping while prices for petro-plastics have been increasing. It is also arguable that bioplastics have the greatest potential for price decreases as a result of on-going advances in process engineering and scale-up, whereas the manufacture of petro-plastics has reached a plateau of efficiency and maturity. Moreover, taking into account other factors, such as the increased supply of bioplastics and the growing awareness of the true disposal costs of petro-plastics, it can be expected that the price differential will become less of an issue.

Technical advances

Advances in technology, such as the application of synthetic biology, can lead to cost savings. One route is through the development of consolidated bioprocessing (CBP), where the multiple steps typically involved to date in the manufacture of bio-products are replaced by a single step and synthetic biology is used to develop engineered micro-organisms to deliver the desired end-products. Typically, biomass conversion processes require enzymes that hydrolyse the carbohydrates present in pre-treated biomass to sugars, and other microorganisms capable of fermenting the liberated sugars into ethanol or other end-products. When suitably engineered micro-organisms both produce the necessary enzymes and ferment the liberated sugars to end-products, the one-step biomass conversion process is called consolidated bioprocessing (CBP).

CBP requires a highly engineered microbial workhorse with many process-specific characteristics. Synthetic biology is the key not only to the development of microorganisms with these characteristics, but also to the design, assembly, and implementation of various synthetic pathways that can lead to the production of novel compounds. A significant advance in the field was published late in 2011, when it was demonstrated that engineered *E. coli* was able to utilise pre-treated switchgrass to produce three advanced biofuels (Bokinsky et al., 2011). The CBP strategy for production of ethanol for bioplastics and the direct production of bioplastics from biomass is thus likely to become a growing focus for research and development.

Resistance to the adoption of new technologies

The level of resistance to bioplastics being produced from genetically modified (GM) sources or developed using new technologies such as synthetic biology is dependent on location. Resistance to the introduction of bioplastics from new technologies produced on a commercial basis is likely to be much higher in Europe compared to, say, North or Latin America. Currently in Argentina, for example, it is accepted that 99% of the soy production is GM (Yankelevich, 2008). In the long term, it is expected that GM technology applications will increase in Latin America, as underlined by on-going research on GM sugarcane in Brazil. In April 2008, the Brazilian Technical Biosafety Committee (CTNBio) approved the first field experiments on GM sugarcane with higher sucrose content (Janssen and Rutz, 2011).

The use of GM sources and new technologies such as synthetic biology in the production of bioplastics is governed to a large extent by regulations and legislation designed to protect the public good. In the European Union, the impact of the governance regime in place on the acceptance and diffusion of GM and other technologies has been more restrictive than in many other parts of the world. As noted by many authors (e.g. Tait, 2009), onerous and lengthy regulatory processes can eventually stultify innovation systems. Finding a balance between the need to stimulate innovation and economic growth and the need to safeguard the interests of the public is thus a key issue for policymakers, especially in a global context in which comparative economic advantage is critically dependent on the risk governance mechanisms in place in different countries.

POLICY OPTIONS FOR THE DEVELOPMENT OF BIOPLASTICS

Supportive environments

Future developments in industrial biotechnology and biorefining will provide the opportunity to start new bio-based industries and transform existing ones. A significant increase in economic activity is expected to result, with new and increased markets for bio-based products (OECD, 2009a).

However, for this to be achieved within the context of a broader, competitive bioeconomy, a supportive environment is needed – creating and maintaining markets for environmentally sustainable products, funding basic and applied research, and investing in multi-purpose infrastructure and education, for example. In addition, this would need to be combined with shorter-term policies such as fostering public dialogue and increasing support for the adoption and use of internationally accepted standards for life cycle analysis (LCA), together with a range of other incentives designed to reward environmentally sustainable technologies (OECD, 2009b).

The last few years have seen, worldwide, a growing number of governments developing a strategy and policy framework to support the development of a sustainable and competitive bioeconomy. Several of these policies offer generic support for the further development of biochemicals, biomaterials and bioplastics, promoting bio-based products or the bioeconomy in general. Most of them focus on research and innovation. Only a few countries have developed a specific set of policies targeting the development of bioplastics.

For this reason, most of the discussion in this document is not specific to bioplastics but also encompasses other bio-based products. A wider bioeconomy context is also provided.

As for any product, several stages can be identified in the development of bioplastics and, for each stage, specific policy instruments may be applicable, for example:

- Research and innovation: supporting research and development through public funding; stimulating technology transfer; supporting demonstrator projects; encouraging market introduction; and providing investment-related subsidies.

- Early market support: protecting against established (conventional) options e.g. (temporary) tax incentives and fiscal measures; supporting the development of communication and governance tools (standards, labels); applying measures to reduce production costs; introducing incentives for the use of process by-products; implementing quotas; and applying tariffs to protect domestic equivalent products (such as the United States 54-cents-per-gallon tariff levied against imported ethanol, now ended).

- Mass market: measures affecting the markets for both inputs and outputs (e.g. measures improving feedstock availability and price, and market pull measures such as public procurement); and waste and packaging legislation, which is key to ensuring appropriate treatment at end-of-life and enabling bioplastics to have access to existing waste collection systems.

Although the current market for bioplastics is growing, its share of the entire plastics production market is rather low (0.4%). Fast growth of the market will only be possible if bioplastics can be produced at a competitive price and if the market can be stimulated (at least temporarily) within the right policy framework.

Policy making for the bio-based economy is complex and touches on several policy areas (Londo and Meeusen, 2010). Several measures and incentives identified by the OECD (OECD, 2011a) that could affect bioplastics include, for example:

- Tax legislation;
- Preferential treatment of products in public procurement programmes;
- Simplified special regulations in waste legislation;
- Opening of community recovery systems for biowaste for compostable bioplastics;
- Government research and development programmes for the co-financing of joint industry/university projects;
- Activities related to communication and market introduction;
- Agricultural policy measures.

Bioenergy and biofuels receive strong support at the commercial production stage via quotas, tax incentives, green electricity regulations and other instruments. Bio-based products and bioplastics could benefit from similar measures, particularly as they currently compete for raw materials with bioenergy products and biofuels. As bioplastics potentially bring with them significant environmental benefits, support for them could make a significant contribution in the context of the global bioeconomy. Alternatively, removing the support mechanism for biofuels would allow bioplastics to compete for biomass resources on equal terms.

Specific options for the development of bioplastics

Mobilising resources for research and development

Within many national contexts, and certainly across national boundaries, many research efforts are fragmented and considerable scope exists for policy initiatives geared towards the reduction of duplication and the creation of critical mass. Weak links between research initiatives and policy mechanisms designed to support activities at other points of the value chain are also endemic to many, if not most, national innovation systems, and this is certainly the case for bioplastics. While increased public funding could help, there is also scope for leveraging private sector investment via the creation of public private partnerships (PPP) in the area of the bio-based products and bioplastics.

Supporting scaling up activities

Access to pilot- and scale-up infrastructures could be supported during the development stage to shorten the time between research and industrial production and commercialisation. Opportunities could also be created for producers of new bioplastics and potential end-users to work together to develop new innovative products and applications, potentially leading to a stronger market pull for bioplastics.

Investing in demonstrator facilities

Investment in demonstrator and pre-competitive facilities could be incentivised in order to support the development of biorefineries dedicated to the production of bioplastics and biomaterials. Access to finance for innovative plants could be mainstreamed and supported by industrial policies in order to increase joint actions by, and synergies between, public and private investors.

Alternative uses for feedstock

Bioenergy and biofuels not only receive a high level of support for R&D and for pilot and demonstration plants, they also receive strong on-going support at the commercial production stage (e.g. via quotas, tax incentives and green electricity regulations). This policy approach leads to market distortions in relation to feedstock availability and cost, placing biomaterials and bioplastics at a relative disadvantage. When energy markets are made more attractive through the use of such incentives and supports, biorefinery development becomes disproportionately focused on energy as the main output and the potential to produce a range of alternative bio-based materials, including bioplastics, is threatened (Carus et al., 2011; EU Ad-hoc Advisory Group for Bio-based Products, 2011). Policy approaches that do not favour the production of bioenergy and biofuels over other potential outputs are needed to stimulate the development of higher added-value products and the more extensive employment opportunities associated with their longer value chains.

Agricultural land productivity

Opportunities exist to improve feedstock production in a sustainable way, e.g. through yield increase, reuse of degraded land, use of unused land, better land management and/or through an improved cropping system.

Incentives for farmers to collect the large amounts of agricultural residues that are generated on farms could help to ensure feedstock supply for biorefinery plants, not only for bioenergy/biofuel production, but for all sectors of the bio-based economy. Such a policy – the Biomass Crop Assistance Programme – is already in place in the United States. This programme provides payments to rural landowners to establish, produce and deliver biomass feedstock (particularly lignocellulosic agricultural residues) to biomass conversion facilities for conversion to heat, power, bio-based products or advanced biofuels.

With such a programme, the establishment and optimisation of infrastructures and logistical capabilities to mobilise all biomass in an environmentally and economically sustainable way can be supported, in particular the technical mobilisation of agricultural waste, residues, lignocellulosic material and non-food cellulosic material.

Alternative cropping systems

In some countries and regions, the development of alternative cropping systems (e.g. the growth of perennial crops and short rotation coppices on under-utilised land) that both optimise land use and focus on the sustainable cultivation of renewable raw materials for the bio-based economy could be encouraged. A recent United States study (Gelfand et al., 2013) demonstrated that land management practices that allow the continued growth of perennial herbaceous species on marginal lands, undisturbed but for harvest and fertilisation, do not involve the release of large amounts of carbon dioxide to the environment and avoid some of the controversies associated with the use of land previously reserved for food crops.

Public procurement

Public procurement is one option that governments can consider when contemplating ways of supporting the development of bio-based products. In the US Biopreferred Programme, for example, bio-based products (including bioplastics) are afforded preference by Federal agencies when making purchasing decisions. When contemplating procurement practices of this nature, preference could be given to the public sector purchase of bio-based products except when: *a)* they are not readily available; *b)* they are available only at excessive cost; or *c)* they do not offer an acceptable level of performance for the specific application. Given its potential power as a demand-side instrument, there is scope for exchange of good practice between countries on bio-product procurement.

Initiatives such as the EU's Lead Market Initiative on Bio-based Products constitute concerted attempts to support innovation via a combination of supply- and demand-side instruments covering standardisation, labelling and certification (the establishment of product performance standards); legislation (an inventory of legislation affecting the sector); public procurement (efforts to encourage green public procurement); and other complementary actions (the setting up of an Advisory Group for Bio-based Products).

Quotas

Just as quotas (the use of indicative or binding targets) are used to stimulate the production and use of bioenergy and biofuels, quotas could be developed for bioplastics. Although setting a target for bioplastics *per se* would be difficult given the breadth of bioplastic product ranges and application areas, time-limited and/or tapering quotas could be introduced for specific bioplastics used either for certain applications or in particular sectors. A good example could be quotas for bio-based plastics, particularly polylactic acid, in the automotive industry, where the use of bioplastics is growing.

Subsidies and taxes

Countries use a variety of direct and indirect measures to support the development of bioplastics, typically involving the use of financial and fiscal incentives to leverage private sector investment. Many countries support R&D either directly (via grants, loans and subsidies) or indirectly (via a variety of R&D tax incentive schemes) and support is also available for other activities. Several countries, especially in Asia (e.g. Malaysia, Japan, South Korea, Singapore and China), offer attractive tax reductions to companies that want to research and invest in this sector.

Standards, labels and consumer awareness

Stringent standards (e.g. EN 13432 or ISO 18606 or EN 14995) can help to ensure that claims made for the properties of bioplastics (such as biodegradability and compostability) are genuine and verifiable by consumers, waste management authorities and legislators. Plain and unambiguous international standards will also be needed in the future to verify claims concerning properties such as bio-based carbon content, recyclability and sustainability.

Harmonised industry standards and clear product labelling could enhance consumer choice by helping to identify goods as ‘bio-based’, ‘renewable raw material’, ‘biodegradable’, ‘recyclable’ or ‘reduced GHG impact’.

Product labels should give clear and reliable information about the environmental performance of bioplastics. Today there are many different ‘eco-labels’[17] in use globally, and definitions and certification procedures differ widely. Harmonisation of eco-labels in the medium term could result in significant gains in terms of consumer confidence and resultant market uptake.

Other measures (e.g. awareness campaigns) could also improve the quality and public availability of information about the ecological advantages of bioplastics, thus helping to strengthen demand.

POLICIES AND PRACTICES BY COUNTRY

This section identifies the policies being used by countries to address issues related to the development and use of bioplastics. Details of international collaborative actions, such as those implemented in the European Union, are also presented.

Argentina

Bioenergy related policies

Argentina is one of the world's top producers and exporters of biodiesel. Argentina's biofuel law 26093[18] of 2006 provides the framework for investment, production and marketing of biofuels. It mandates that gasoline and diesel be mixed with 5% biofuel as from January 2010, thus helping to secure a market for the domestic supply of grain-based fuels. Companies producing for the home market are also able to take advantage of various tax incentives that are not applicable for export markets.

Since 2007, Argentina has had a regulatory framework in place to promote the production and use of biofuels. The main objectives of this framework are to diversify the supply of energy, to become more environmentally friendly, and to promote the development of rural areas (primarily non-traditional production areas), especially to benefit small and medium sized agricultural producers.[19]

In January 2008, Congress passed Law 26334, which promotes the production of bioethanol from sugar cane. This allows sugar mills to benefit from the biofuel promotional regime if they abide by the basic norms and regulations of the biofuel law.

Brazil

Plastic bag related policies

"Saco é um saco" is a campaign spearheaded by the Brazilian Ministry of Environment to decrease the consumption and disposal of plastic bags in the country. The first phase of the campaign entailed raising consumer awareness on the impact of excessive consumption of plastic bags. The campaign is now at a second phase, focusing on showcasing eco-friendly alternatives to disposable plastic bags, such as reusable packaging.

Fiscal and financial supports

By providing tax breaks and subsidies to sugarcane farmers, investment increased and large distilleries developed to convert the crop to ethanol, especially in the state of São Paulo. In the 1990s, the government withdrew its subsidies and lifted price controls on ethanol, creating the world's first self-sustaining market. The use of leading-edge technology and highly efficient operations at distilleries also means that Brazilian sugarcane ethanol delivers a clear cost advantage. These cost and resource advantages are attracting investor interest in the industry as well as increasing efforts by companies to use ethanol to create products other than fuel. Bioplastics production in Brazil is very attractive due to its cost competitiveness and positive demand drivers, such as increased consumer interest in environmentally friendly packaging and a greater emphasis on sustainability on the part of product manufacturers worldwide (Morales et al., 2009).

In February 2012, the Brazilian Agriculture Ministry released a Strategic Plan for the sugar-energy industry, including a series of measures involving credit and financing via government funds, available to the sugarcane industry at market rates. In a related move, in January 2012, the Brazilian development arm, BNDES, created a new programme to encourage the production of sugarcane by financing the renovation of old sugarcane farms and the expansion of the cultivated area, with a budget of BRL 4 billion (approximately USD 1.75 billion).

Infrastructure policy

The government of Brazil launched a growth acceleration programme, the Programa de Aceleração do Crescimento (PAC)[20], in 2007 and spent over USD 220 billion through 2010 on infrastructure, funded by the federal government and by state-owned and privately owned companies. In 2010, the project was continued with a second phase (PAC 2), promising USD 526 billion from 2011 to 2014 and USD 346 billion after 2014 to improvements in energy, transportation, urban infrastructure, housing, sanitation, electricity and social programmes. While the programme is designed for the whole economy and not just the bioplastics industry, it is expected to drive the growth of the bioplastics industry.

Investment in research at both the federal and state levels is another important part of economic development. The Institute for Technological Research (IPT),[21] a public organisation supported by the State of São Paulo, is one of Brazil's largest research institutes. The institute's Laboratory of Chemical Processes and Particle Technology (LPP) in the Centre for Processes and Products Technology (CTPP) provides technological support to processers, helping with projects in formulation and recycling. Another part of CTPP, the Laboratory of Industrial Biotechnology (LIB), works to develop new polymers based on renewable resources. Current work includes increasing the scale of bioreactors, using enzymes and solvents to extract and purify biopolymers, characterising biopolymers, and developing polymers for controlled delivery of active pharmaceutical ingredients.

The São Paulo Research Foundation (FAPESP),[22] funded by state taxes as mandated by the state constitution, has been supporting scientific and technological research in São Paulo for 50 years. FAPESP's Partnership for Technological Innovation (PITE) funds several innovative research programmes in plastics, many of which target materials produced from renewable resources.

Bioenergy related policies

Brazil has a long history of using biofuels as an energy source. Bioethanol has been commercially produced there for over 75 years. The sector is completely deregulated, but the government plays a key role in influencing how much ethanol is produced in order to guarantee the domestic supply for both products through the ethanol use mandate and tax incentive measures.[23]

The introduction of biodiesel in the energy matrix is a more recent occurrence. The biodiesel programme was created in 2004 to partially replace fossil fuels use and to promote social inclusion. The market remains regulated by the Brazilian government through a public auction system which sets the volume of biodiesel that should be produced as well as the average sales price. The government has also set the biodiesel mandate and tax incentive measures to stimulate the sector.

Trade policy

The Brazilian Trade and Investment Promotion Agency (Apex-Brasil) seeks to increase exports of Brazilian products in a wide range of industries, including plastics. The Export Plastics Programme[24] was created in 2004 to encourage Brazilian plastics converters to develop and expand their export businesses and establish international operations. The programme is coordinated by the Brazilian Plastic Institute (INP), a non-profit organisation, and is funded by Apex-Brasil, which invested nearly USD 2.5 million in 2010 and 2011, and by others throughout the plastics value chain, such as Petrobras and Braskem. The programme has more than 70 member companies that export to more than 30 countries in Europe, North and South America, and Africa.

Bulgaria

Plastic bag related policies

The Bulgarian Parliament recently approved a law that places an eco-tax on plastic bags, in an effort to drastically reduce the number of traditional plastic shopping bags.

Canada

Plastic bag related policies

In Canada, plastic bags will be banned in Toronto starting in 2013. The ban includes "those advertised as compostable, biodegradable, photodegradable or similar".

Bioeconomy related policies

In July 2011, a Bioeconomy Committee was formed in British Columbia (BC), Canada. The Committee concluded that there is an urgent need for the government to take a leading role in the further development of British Columbia's bioeconomy. The Bioeconomy Committee formulated a set of recommendations for government to hasten the productive economic development of BC's bioeconomy sector (BC Bioeconomy Committee, 2012). The main pillars of the recommendations aim to:

- Establish a clear, long-term bioeconomy vision;
- Improve access to fibre and feedstock;
- Establish a technology development strategy;
- Develop markets for BC bioproducts and aggressively market BC's advantages;
- Integrate the bioeconomy infrastructure needs into provincial initiatives.

Bioenergy related policies

In July 2007, the Canadian government announced that it would provide up to USD 1.5 billion in incentives over nine years to producers of renewable alternatives to gasoline and diesel fuel. The incentives are primarily for producers to bridge the gap between the current production level and the 3,000 million tonnes/year that will be needed to meet the 2012 targets, which were set by the government in December 2006 and passed into law in May 2008: reaching an average of 5% renewable content in gasoline by 2010 and 2% renewable content in diesel fuel and heating oil by 2012.

Federal incentives provided through excise tax exemptions amount to USD 0.10 per litre for bioethanol and USD 0.04 per litre for biodiesel. A National Biomass Expansion Programme provides USD 140 million in contingent loan guarantees to encourage financing for new plants that produce bioethanol from biomass material such as crop residues.

Government initiatives include:

- The ecoAgriculture Biofuels Capital Initiative (ecoABC), which is a federal USD 200 million, four-year capital grant programme that provides funding for the construction or expansion of transportation biofuel production facilities. Funding is focused on cellulosic bioethanol.

- The ecoENERGY for Biofuels Initiative, which is scheduled to invest up to USD 1.5 billion over nine years from 2007 to boost Canada's production of biofuels.

China

Bioeconomy related policies

China recently included the bioeconomy as a priority within its 12th Five-Year Plan for Energy Saving and Emission Reduction, aiming to transform the mode of economic development, establish an energy-saving and environmentally friendly society and strengthen the capacity of sustainable development. During the coming five years, China has pledged to invest more than USD 316 billion in promoting energy-saving and low-carbon projects across the country. Also stressed in the Plan is the need to accelerate China's bioeconomy to serve major needs in health, agriculture and environmental protection. For the first time in a five-year plan, China has also set a target for the reduction of carbon intensity, which could also affect the plastics sector (MEP, 2012).

Research and development policies

Biodegradable plastics receive substantial political and research support in China. The National Development and Reform Commission has set up a biomass special equity fund, and institutions such as the Institutes of Physics and Chemistry of the Chinese Academy of Sciences, Tsinghua University, and Sichuan University are actively engaged in research. China has also encouraged the development of polylactic acid (PLA) materials.

Overcoming investment barriers: taxes and subsidies

In China, feedstock prices are regulated, reportedly held below international levels, and sometimes frozen. Support for bio-based chemicals includes numerous incentives for producers and a preferential tax treatment for selected firms in emerging biochemical industries (OECD, 2011a). In addition, since 2005, a specific programme promotes production and consumption of biodegradable plastics (Clever Consult, 2010).

Denmark

Plastic bag related policies

In 1994, Denmark established a tax on plastic and paper bags that is paid by retailers, leading to the strong promotion of reusable bags by retailers.

France

Bioeconomy related policies

In 2005, the French General Directorate for Competitiveness, Industry and Services created the so-called Competitiveness Clusters. These bring together companies, research centres and educational institutions in order to develop synergies and co-operative efforts, including some relevant to the bioeconomy. The French Government complements cluster development by allocating financial support to the best research and development and innovation platform initiatives. One of the clusters is the 'Industries and Agro-Resources' Cluster or IAR.[25] This cluster unites stakeholders from research, higher education, industry and agriculture in the Champagne-Ardenne and Picardy regions of France around a shared goal, the value-added non-food exploitation of plant biomass. In order to achieve this ambitious objective, the IAR cluster has defined four strategic fields of activity around the biorefinery concept: bioenergy, biomaterials, biomolecules and green ingredients. A large number of international-scale research and development projects have already been launched covering the four target markets and there are also links to international clusters in countries including Canada, Finland and Hungary.

Toulouse White Biotechnology (TWB)[26] is a PPP that was created in 2011, granted by the French National Agency for Research the level of EUR 20 million over 10 years. Its mission is to design and build the biological tools (e.g. enzymes and microorganisms) required for the novel production of biofuels, biopolymers and biomaterials using renewable carbon, to contribute to the development of the bio-based economy. The thrust of TWB is to use the PPP for advancement from research to pre-industrial demonstrator, founded upon 20 private companies, 5 investors and 9 public partners and local authorities. A novel aspect of TWB is the Bio-Ethic Evaluation Platform, which examines the social acceptance of products and processes.

Germany

Plastic bag related policies

In Germany, all stores that provide plastic bags must pay a recycling fee to a dual system for enhancing recycling programmes and running source-separated packaging waste collection and recycling schemes.

Bioeconomy related policies

The Bioeconomy Research and Technology Council (BÖR, BioÖkonomieRat)[27] is funded jointly by the Ministry of Education and Research and the Ministry of Food, Agriculture and Consumer Protection. It is an independent advisory body to the German government for all matters relating to bioeconomy. The Council is made up of experts from university and non-university research institutes, from the federal government's own departmental research sector and from research in the private sector. The missions of the Bioeconomy Council are to accelerate the development of innovative technologies and identify the need for future research. Another task of the Council is to analyse the strategic goals of Germany as a whole, and its individual Regions. The BioEconomy Council's first term has been set at three years and is supported by an office in Berlin.

The aims of the BioEconomy Council are:

- To offer an overview of the opportunities and prospects of the bio-economy in Germany;
- To deliver scientifically-based recommendations for measures to deliver sustainable solutions to global challenges;
- To develop a supportive environment for research, education and training, and student support;
- To help strengthen networks of relevant actors from science, business and politics with a view to achieving maximum harmonisation on strategic questions.

In 2010, the Council published the *Bio-economy Innovation Report* (BÖR, 2010) placing emphasis on increasing biomass yield volumes and more efficient production processes in the food and energy sectors. Two reports with recommendations have also been published: the report *Combine Disciplines, Improve Parameters, Seek Out International Partnership* (BÖR, 2009) suggested a restructuring of research funding and recommended incentive systems for private investment, and, in the report *Priorities in Bio-economic Research* (BÖR, 2011), the BioEconomy Council defined the priorities with regard to relevance and urgency of the research topics. The Council has recently been very critical about the focus on bioenergy alone, arguing for more actions to encourage industrial biomass use (BÖR, 2012). Germany has also developed an *Action plan for the industrial use of renewable raw materials* (BMELV, 2009).

In 2007, the German Federal Ministry of Education and Research initiated the creation of five German regional industrial biotechnology clusters. Among these clusters is CLIB2021[28] (co-founded with the Ministry of Innovation, Science and Research of the German State of North Rhine-Westphalia) with 32 founding members. Since then the cluster has grown to include more than 70 academic institutions, companies and investors, has launched research and development projects with a total volume of EUR 50 million, has founded 5 start-ups and 10% of its members are international. Another cluster is Biom Wb[29] with two demonstration plants for cellulosic ethanol and acetic acid, a new multi-purpose pilot plant and a degree programme in industrial biotechnology at the Technical University of Munich.

Israel

Plastic bag related policies

In June 2008, the Israeli government enacted a tax on plastic bags, payable as a charge to the consumer.

Ireland

Plastic bag related policies

In 2002, Ireland was one of the first European countries to introduce a tax on plastic shopping bags payable by the consumer. Since then there has been a levy of EUR 0.15 on each bag, previously provided free of charge to customers at points of sale (Convery et al., 2007).

Bioeconomy related policies

The year 2008 saw the publication of *Towards 2030 – Teagasc's Role in Transforming Ireland's Agri-Food Sector and the Wider Bioeconomy* (Teagasc, 2008). The four pillars are: food production and processing; value-added food processing; agri-environmental products and services; and energy and bioprocessing. In addition, in 2009, the Irish Government published *Developing the Green Economy in Ireland* (Forfás, 2009). The key actions in this strategy paper are to:

- Promote green sectors that drive exports and job creation (e.g. renewable energy, energy efficiency and management, waste management, water/wastewater);
- Deliver green zones and a green international financial services sector (IFSC);[30]
- Create world-class research centres and human capital;
- Remove hurdles to the development of the green economy (e.g. technical, regulatory and planning barriers to the development of renewable energy projects; implementing green public procurement in Ireland; ensuring that green firms can access finance; and developing Ireland's brand).

Italy

Plastic bag related policies

Italy has banned the distribution of traditional plastic carrier bags, allowing only the commercialisation of biodegradable single use and long-life reusable bags (Environmental Leader, 2011).

Box 1. Italy - Substituting traditional plastic carrier bags with biodegradable and compostable bags in compliance with EN 13432.

In January 2011, Italy promoted a first of its kind regulation aimed at replacing traditional plastic carrier bags with biodegradable and compostable bags (compliant with the harmonised CEN Standard 13432) and reusable long-life bags. This initiative represented an example of how innovation and growth in the field of bio-based industries can be achieved by legislative *ad hoc* measures that encompass environmental benefits and stimuli for investments and job creation.

A - Main policy references

- DL152/2006: 65% separate collection in 2012. Organic waste to be collected either in biodegradable and compostable bags (EN13432) and paper bags or in bins;
- Financial law 2007: Shopping bags since January 2011 have to be either biodegradable and compostable or reusable ;
- New law 28, 24/3/2012: non-reusable shopping bags have to be certified by accredited bodies as biodegradable and compostable according to the norm EN13432. There is an additional threshold thickness for reusable bags.

B - Challenges and opportunities posed by the new legislation

- Opportunity to re-launch a green chemical industry based on added value products in synergy with the traditional chemical industry;
- Need to deal with market growth acceleration;
- Need to support the sustainable use of shopping bags promoting at the same time organic waste management and quality compost ;
- Trigger construction of new plants for composting and treatment of biowaste as a consequence of higher rates of biowaste collection;
- Catch opportunities for bioplastics in applications responsible for pollution of organic waste (i.e. produce bags, cling film; catering products,);
- Create new local integrated industrial opportunities;
- Build potential alliances with the chemical industry to create new opportunities.

C - One year after: the impact of carrier bag legislation on industry, citizens and environment.

Compost and biowaste management:

- Increase in the quality and purity of compost in composting sites given the decreased quantity of plastics bags in waste streams (Italy is the second largest compost producer in Europe and accounts for 4 million tonnes of municipal organic waste produced every year, of which 1.4 million tonnes are transformed into compost and used as organic fertiliser);
- The percentage of organic waste present in food waste bags increased from 90.3 to 98.5% (Centemero, 2012);
- Compost as a result is less contaminated by plastic waste and the 8% fewer impurities contribute to reducing the presence in composting sites of 180 000 tonnes of plastic residues.

New investments in bioplastics in Italy: positive cascade effects along the value chain:

- New capacity of biodegradable polyesters of more than 200 000 tonnes in Europe;
- New plants and projects under development/construction in Italy with high investment from private companies;
  - In Italy two chemical sites have been converted in Lazio and Umbria;
  - Two new fermentation plants in Piedmont (bio-succinic acid) and Veneto (bio-BDO) and an integrated biorefinery in Sardinia are under construction (about EUR 700 million is expected to be invested between 2012-2015 in research and development and pilot and demonstration plants in the field of bio-based products);
  - Matrica JV Novamont-ENI for the creation of a large green chemistry hub in Europe: 50/50 J-V between Polimeri Europa/ENI and Novamont for the transformation of the Porto Torres chemical site of ENI into a third generation biorefinery for the production of bioplastics, biolubricants and biofillers/additives for low rolling resistance rubber. The biorefinery will directly employ about 680 people with significant indirect and direct effects on the local areas;
- Production of biopolymers in the carrier bags sector increased from 8% in 2010 to 28% in 2011. The sector is hence strengthening its role and contribution to the achievement of a strong bioeconomy in Italy all along the value chain. Moreover revenues for the carrier bags sector increased from EUR 674 million in 2010 to EUR 732 million in 2011 (data from Plastic Consult and a study commissioned by Assobioplastiche, the Italian Association for Biodegradable and Compostable Plastics);
- In 2011, start-up of first dedicated cultivations by SINCRO (a joint venture between Novamont and a cooperative of 600 farmers of the COLDIRETTI Association) in Umbria for biolubricants in agriculture and by Novamont in Sardinia to feed the Matrica biorefinery.

Citizens attitudes and sustainable behavioural changes:

- Italian citizens were induced to adopt behaviour that has a positive impact on environmental sustainability. Recent estimates show that 94% of Italian citizens believe that the law is an important milestone and step towards environmental improvement (ISPO, 2011);
- The law has helped to build widespread citizen awareness of the need to protect the natural environment and the fundamental role played by innovation in this respect. Estimates show that 88% of Italian citizens recognise that biodegradable and compostable plastics are a key innovation capable of triggering multiple positive effects (ISPO, 2011).

Bioeconomy related policies

Since the launch of the European Union Bioeconomy Strategy, the Minister of Economic Development in Italy has set up a working group on green chemistry with the aim of elaborating a strategy at a national level. In May 2012, the Ministry of Education, Universities and Research launched a call for implementing clusters focused on top innovative sectors for the country, one of them being green chemistry. The cluster currently has 114 members (public and private), including the Italian Federation of Chemical Industries. It has about EUR 50 million of public and private funds addressing the finance of parallel, complementary three year R&D projects along with training projects for Masters students, PhD students and young scientists in the area of green and sustainable chemistry, biomaterials and industrial biotechnology. Furthermore, it will have the responsibility to develop the strategic R&D agenda and the implementation action plan on a bio-based economy for Italy.

Japan

Policies specific to bioplastics

Following the ratification by the Japanese Government of the Kyoto Protocol in June 2002, the Government announced (December 2002) two measures: the *Biotechnology Strategic Scheme* and the *Biomass Nippon Strategy*. The main objective of the two measures was to promote the utilisation of biomass and to reduce the consumption of fossil resources and to mitigate global warming through the use of biotechnology. The policy objective stated in the *Biotechnology Strategic Scheme* is to replace approximately 20% (2.5 to 3 million tons per year) of conventional plastics with plastics from renewable resources by 2020. The *Biomass Nippon Strategy* was revised in March 2006 to accelerate the growth of biomass towns and to promote the utilisation of biofuels.

The *Biomass Nippon Strategy* has prompted companies such as Toyota and NEC to accelerate their levels of research and development into bio-based plastics and to raise the bio-based content of their products. Japanese vehicle manufacturer Toyota is planning to switch 20% of the plastics used in its vehicles to bio-sourced plastics by 2015 and expects bioplastics to help in its efforts to accomplish its company-wide goal of reductions in CO_2 emissions (Mirasol, 2010; OECD, 2011a).

To help to develop the market for bioplastics, the Japan BioPlastics Association (JBPA) started a certification programme for products containing biomass-based plastic content. The association has established standards as well as a methodology for the analysis and the evaluation of these plastics. The programme includes a logo easily recognisable by consumers. The JBPA certification, called BiomassPla, specifies that products with the logo must contain 25% bio-based plastic by weight. So far, JBPA has certified about 900 biodegradable plastic products in Japan. The system is based on a positive list system for all components, biodegradability specifications based in Japanese Industrial Standards, safety certification of all components and proof of no hazardous effects to soil (Chanprateep, 2010).

Research and development policies

Every five years, a new Science and Technology Basic Plan is drawn up in Japan to support the promotion of science and technology. The 4th Science and Technology Basic Plan (2011-2015) sets out the current priorities. At a budgetary level, it sets a target of 4% of GDP dedicated towards expenditure on research and development by 2020. Of this, 3% is to be by industry and 1% by government. The total government expenditure over the duration of the plan is to be around EUR 240 billion, assuming nominal growth of 2.8%. The 4th plan positions green innovation for environment and energy as one of the two major pillars of growth, (the second being life innovation, to effect milestone advances in medicine, health and care-giving). The government will promote green innovation with the aim of addressing climate change issues facing Japan and the world and realising the world's most advanced low-carbon society (Council for Science and Technology Policy, 2010).

Conventional biotechnologies have played a critical role in Japanese industry over the last few decades. In the past, Japan has tried to select technologies and industries relevant to its future and has set up bureaucratic structures to support this redirection. The RIKEN Biomass Engineering Programme (BMEP)[31], for example, has developed a ten-year plan from 2011 for research and technological development designed to establish innovative bioprocesses that will transform biomass to chemical materials and bioplastics.

Bioenergy related policies

Following its ratification of the Kyoto Protocol, Japan began to move rapidly towards the promotion of biofuels to meet its commitment to reduce CO_2 emissions by 6% from the 1990 level by 2012. Accordingly, in March 2006, Japan revised the *Biomass Nippon Strategy* to emphasise the use of biofuels for transportation. It set a goal of replacing fossil fuels with 500 000 kilolitres (Kl) (oil basis) of biofuels for the transportation sector by 2017.

In February 2007, the Executive Committee on *Biomass Nippon Strategy* released a report entitled, *Boosting the Production of Biofuels in Japan*. The report indicated that Japan will be able to produce 6 million Kl of biofuels domestically by around 2030 if appropriate technological advances are realised. It sets a target of producing 50 000 Kl of biofuels from molasses and off-specification rice, and 10 000 Kl of biofuels from construction waste by 2011. In addition, the report sets a goal of producing 6 million Kl of biofuels per year, 10% of domestic fuel consumption, from cellulosic materials such as rice straw, wood and resource crops such as sugar cane and sugar beet by around 2030. This ambitious target is based on an estimate that Japan has unused biomass resources (non-edible portions of farm crops and forestry residues) equivalent to 14 million Kl of oil, and that it could produce resource crops equivalent to 6.2 million Kl of oil by fully utilising abandoned arable land, which is estimated at 386 000 ha.

Korea

Policies specific to bioplastics

In 2012, the Korean government announced a "Strategy for promotion of industrial biotechnology", with the goal of establishing a mid- to long-term strategy to develop related technology and devise detailed measures for implementation, contributing to lowering the existing dependence of the economy on crude oil. By 2020, this effort is expected to result in replacing 4.8% of crude oil imports with biochemical product manufacturing, reducing carbon dioxide emissions by approximately 10.8%, and generating at least 43 000 new jobs.

Several companies have made the decision to use biobased materials in their product lines. Samsung Electronics has produced a mobile phone that uses a bio-based material externally. LG Hausys has produced flooring and wallpaper that uses PLA material. Furthermore, SK Chemical has produced a heat-resistant bioplastic product, and Hyundai Motors plans to replace interior material partially in their new models with bio-based material.

The Korea Bioplastics Association (KBPA)[32] has established an authentication programme for products made of, or based on, biomass in order to expand the understanding of bioplastics and promote supply. KBPA's authentication system is called "BiomassPlastic Certification", and can be attained only when more than 25% of a product consists of biomass-derived ingredients. The Korea Biomaterial Packaging Association (KBMP)[33,] is also operating a bioplastic certification scheme. The Korean government is recommending that these two programmes be united. Furthermore, the government has a plan to review a preferred procurement system for public institutions for authenticated products, and the establishment of an insurance system for trade in order to expand exports.

Research and development policies

Some research programmes are now in progress supported by the government: the development of technology for manufacturing of biomass-based C3 platform compounds; the development of technology for production of heat resistant bioplastic; the development of technology for production of 2,3-butanediol and derivatives; and the development of materials using woody biomass-based polymers.

In addition, the government plans to implement the “Industrial Biotech 2.0: Green Carbon Korea Project” from 2014, investing around KRW 250 billion (approximately USD 222 000 000) for 5 years. The purpose of this project is to create a green carbon-based industrial biotechnology in Korea, and to reduce the crude oil dependence of the five core industries (electric/electronic, automobile, petrochemical/refinery, textiles and industrial materials).

Regarding application research, while the government is pursuing the establishment of a “White Biotech Application Centre” in the province of Cholla-Bukdo, aided by the central government, there are also plans to form a “Bio-kombinat Positive Research Centre” to develop processing technology for the production of a variety of products related to green carbon.

Bioenergy related policies

The Korean government implemented the "Biodiesel Test Provision Project" in 2002, to increase energy security, reduce air pollutants, and lower greenhouse gas levels by cutting dependence on oil. From 2012, in accordance with the Renewable Fuel Standard (RFS), diesels for transportation must contain 2% biodiesel. This mandatory composition level will be continuously increased going forward. Through the Renewable Fuel Standard, the government is providing consistent tax support, and many companies, including SK Chemical, GS Bio, Samsung Petrochemical, are investing in the biodiesel industry.

Malaysia

Bioeconomy related policies

The Malaysian Government recently announced a new Bioeconomy Initiative Malaysia (BIM), a comprehensive plan to encourage commercialisation in the biotechnology industry. Endorsed by Malaysia's Biotechnology Implementation Council and launched by the Prime Minister of Malaysia in November 2011, BIM is the framework for the nation to develop a high-income bioeconomy through a sustainable ecosystem of research and development and commercialisation in the areas of agriculture, healthcare and industrial biotechnology by 2020. Action areas include: medical biotechnology, including production of vaccines, medical devices and biopharmaceuticals; industrial biotechnology, including energy and bio-based chemicals; and agricultural biotechnology. The Malaysian Government expects that the Bioeconomy Initiative will generate around 20 000 job opportunities by 2020 in the entire biotechnology ecosystem and related value chain (MOSTI, 2011).

A complementary policy, the National Biomass Strategy 2020, outlines how Malaysia can develop new biomass sectors with the aim of creating higher value-added economic activities that can contribute towards gross national income and create skilled jobs (Agensi Inovasi Malaysia, 2011).

Netherlands

Bioeconomy related policies

In the Netherlands, the Cabinet of Economic Affairs, Agriculture and Innovation has decided that the bio-based economy is one of the emerging economic pillars to be supported. The development of the national strategy was the result of an on-going interaction between business, society and science, stimulated by policymakers. In April 2012, the Cabinet presented a mid- and long-term vision and strategy for the bio-based economy (Dutch Cabinet, 2012).

The "innovation contract bio-based economy" is a joint agenda developed by industry and research organisations. It contains six work packages, each covering the entire innovation chain (from more basic research to valorisation). 'Bio-based materials' is one of the work packages. In total, more than 100 companies will participate in the projects and have committed more than EUR 200 million (Innovatiecontract Bio-based Economy 2011-2016, 2011).

BE-Basic[34] (Bio-based Ecologically Balanced Sustainable Industrial Chemistry) is a public-private partnership (PPP) that develops industrial bio-based solutions for a sustainable society and has a research and development budget of more than EUR 120 million. Half of this is funded by the Ministry of Economic Affairs, Agriculture and Innovation. BE-Basic was founded early in 2010 and maintains an international focus via strategic partnerships with a select number of countries: Brazil, Malaysia, United States and Vietnam.

Norway

Research and development policies

A Norwegian Industrial Biotech Network[35] was set up in mid-2012. Its main objective is to stimulate innovation through partnerships and dissemination of knowledge. The network will connect academia and industry across research disciplines, industry sectors and geography. The network is the result of a joint initiative by Innovation Norway, the Research Council of Norway and SIVA (Industrial Biotech Network Norway, 2012).

In February 2011, a memorandum of understanding was signed between Innovation Norway and the Technology Strategy Board in the United Kingdom. This collaboration agreement aims to foster transnational collaboration between industries and research institutions in the area of industrial biotechnology and biorefining. In 2012, it was decided to work together to support nine new research and development projects to create innovative processes to generate high-value chemicals through industrial biotechnology and biorefining. The United Kingdom Technology Strategy Board has offered grant funding totalling GBP 1.82 million to the nine United Kingdom-led projects (four full-scale collaborative research and development projects and five feasibility projects) and four of these will also be supported by Innovation Norway, which is providing additional funding of GBP 400 000 to the Norwegian businesses that are taking part. The projects will look at how industrial biotechnology and/or biorefining can be competitively applied to the production of high value chemicals and will see collaboration between industrial biotechnology developers, higher education institutions and the chemicals sector.

Spain

Bioeconomy related policies

The Spanish Technological Biomass Platform (BIOPLAT) was launched in 2007 with support from the former Ministry of Science and Innovation and the Ministry of Economy and Competitiveness. Its objective is to provide a framework in which all sectors involved in biomass can work together and in a co-ordinated way to achieve the successful commercial establishment of biomass-related initiatives in Spain, with steady and continuous growth in a competitive, sustainable and properly regulated manner.

The Platform of Biotechnological Markets is a biotechnology platform set up by ASEBIO (The Spanish Association of Bio-Companies) with support from the former Ministry of Science and Innovation and the Ministry of Economy and Competitiveness. It was launched in 2010 with the objective of setting up stable, efficient and multilateral communication channels between the different stakeholders of the science-technology-company system, as a way to foster biotechnology innovation, technology transfer and translation to society. The science-technology-company system has innovating elements for financing, defining, and solving regulatory issues to turn them into a real opportunity for the biotechnology business sector.

The Spanish Sustainability Observatory (OSE) is an independent organisation created in 2005 in collaboration with the Ministry of Agriculture, Food and Environment, the Biodiversity Foundation and the General Foundation of the University of Alcalá. It has many indicators regarding socio-economic and development, eco-efficiency and development of agriculture and fishing, industrial sector and homes.

Sweden

Bioeconomy related policies

In February 2012, the Swedish Government prepared a "Swedish Research and Innovation Strategy for a Bio-based Economy" (FORMAS, 2012). The following research and development needs were defined:

- The replacement of fossil-based raw materials with bio-based raw materials;
- Smarter products and smarter use of raw materials;
- Change in consumption habits and attitude;
- Prioritisation and choice of measures (e.g. environmental consequences, socio-economic consequences and governing policies).

Thailand

Policies specific to bioplastics

Thailand is a biomass-rich country with abundant feedstock resources and more than 4 000 companies in the plastics industry. Since 2006, the Thai Government has declared the bioplastics industry to be one of the strategic industries that the Government is promoting in its drive towards sustainable growth and development. This resulted in 2008 in a *National Roadmap for the Development of Bioplastics Industry*, developed by the National Innovation Agency (Ministry of Science and Technology). This action plan for 2008-2012 was focused on four main strategic areas:

- Sufficient supply of biomass feedstock;
- Accelerating technology development and technology co-operation;
- Building industry and innovative businesses;
- The establishment of supportive infrastructure.

The strategies covered the entire value chain of the bioplastics industry. The roadmap provided targets, indicators and action plans and designated sectors and organisations for implementation. The total budget for the roadmap strategies at that time was USD 60 million.

Examples of incentives for investment in bioplastics included:

- A corporate income tax exemption for eight years and additional 50% reduction for five years;
- Deductions for infrastructure construction and installation costs;
- Import duty reductions or exemptions for machinery and raw materials;
- Permission to bring in foreign experts and technicians.

These Government initiatives and incentives have led to several investments in production facilities by both international and domestic firms. The Thai Government has also encouraged Thai companies to engage with international bioplastics companies and has promoted close collaboration with international partners. In addition to investment incentives, other government policies have promoted the use of bioplastics and the development of Thai industrial standards for bioplastics and consumer awareness (Ministry of Science and Technology of Thailand, 2008).

More recently, the Thai Cabinet has approved additional supportive measures to boost investments in this sector, such as a USD 10 million grant for the construction of a pilot bioplastic resin production facility. The rest of the investment is to come from the local private sector, and the facility will become operable by 2013. In addition to the pilot plant construction, supportive measures to enhance commercial investments in the local bioplastics industry over the period 2011-2015 will target five areas:

- Biomass availability;
- Bioplastics research and development;
- Standardisation system;
- Business and investment privileges;
- Market promotion and environmental management.

A total of USD 20 million has been committed by the Thai Government to support the implementation of these supporting measures in the five areas. It is expected that development of the local bioplastics industry will take place in accordance with the National Roadmap.

United Arab Emirates

Plastic bag related policies

The United Arab Emirates (UAE) has banned all shopping bags that are not oxo-photodegradable.

United Kingdom

Research and development policies

In the United Kingdom, the Technology Strategy Board has created an Industrial Biotechnology Special Interest Group (IB-SIG) to operate across its networks to implement the recommendations of the 2009 Industrial Biotechnology Innovation and Growth Team (IB-IGT, 2009).

Also in the United Kingdom, the Integrated Biorefining Research and Technology Club (IBTI Club) was launched in 2009. This group consists of a research and technology partnership involving the Biotechnology and Biological Sciences Research Council (BBSRC), the Engineering and Physical Sciences Research Council (EPSRC), the Bioscience for Business Knowledge Transfer Network (KTN) and industry. The club will interface with the KTN's wider Integrated Biorefinery Technologies Initiative (IBTI) and will invest around GBP 6 million in industrially relevant, innovative, basic biological, chemical and engineering research in biorefining technologies.

United States

Bioeconomy related policies

In April 2012, the Obama administration announced a broad plan to foster development of the bioeconomy, the *National Bioeconomy Blueprint*, including the use of renewable resources and biological manufacturing methods. The blueprint is aimed at fostering all biology-based businesses, including pharmaceuticals and medical devices (The White House, 2012).

The *National Bioeconomy Blueprint* describes five strategic objectives for a bioeconomy with the potential to generate economic growth and address societal needs:

- Support for research and development investments that will provide the foundation for the future US bioeconomy;
- Facilitate the transition of bio-inventions from research lab to market;
- Develop and reform regulations to reduce barriers, increase the speed and predictability of regulatory processes and reduce costs;
- Update training programmes;
- Identify and support opportunities for the development of public-private partnerships and pre-competitive collaborations.

Specific to biochemicals and bioplastics, the Blueprint mentions: increasing the availability of bio-based products via funding for biomass research at United States Department of Agriculture (USDA), Department of Energy (US DOE) and Advanced Research Projects Agency-Energy (ARPA-E); transforming manufacturing through bio-innovation; and driving innovation through bio-based and sustainable product procurement by strengthening the bio-based markets programme.

Infrastructure

The United States administration has decided to stimulate industrial biotechnology as part of its governmental programme and has allocated a substantial budget to the drafting of a plan to facilitate further development and implementation of the use of this form of biotechnology. Budgets are being set aside for research programmes on enzyme and biomass technologies as well as bio-based products and bioenergy. The United States is not only funding research but also scaling-up, pilot and demonstrator projects.

The Biomass Research and Development Act of 2000, later amended by Section 9001 of the Food Conservation and Energy Act of 2008, established the Biomass Research and Development Board and a Technical Advisory Committee. The projects funded will help to develop economically and environmentally sustainable sources of renewable biomass and increase the availability of renewable fuels and bio-based products.

On 5 May 2009, the US DOE announced plans to provide USD 786.5 million from the American Recovery and Reinvestment Act as additional funding for commercial-scale biorefinery demonstration projects. The projects selected will work to validate integrated biorefinery technologies that produce advanced biofuels, bioproducts, and heat and power in an integrated system, thus enabling private financing of commercial-scale replications. A further USD 176.5 million will be used to increase the federal funding ceiling on two or more demonstration or commercial-scale biorefinery projects. In December 2009, an additional investment of USD 600 million in advanced biorefinery projects was announced (KET Working Group, 2011). An overview of the US Department of Energy grants for biorefineries has been published (OECD, 2011a).

Public procurement

The USDA[36] BioPreferred programme[37] was created by the Farm Security and Rural Investment Act of 2002 (FSRIA) and re-authorised by the Food, Conservation, and Energy Act of 2008 (frequently referred to as the 2008 Farm Bill) to increase the purchase and use of bio-based products. The USDA manages the BioPreferred programme, which comprises two elements:

- Preferred procurement programme for federal agencies and their contractors;
- A voluntary labelling programme for the widespread consumer marketing of bio-based products.

Under the procurement programme, BioPreferred designates categories of bio-based products that are required for purchase by Federal agencies and their contractors. As a part of this process, the minimum bio-based content is specified, and information on the technical, health and environmental characteristics of these products are made available on the BioPreferred website.

A bio-based product is composed wholly or significantly of biological ingredients. To be designated by the BioPreferred Programme, a product must meet or exceed USDA guidelines for its product category. The bio-based content is determined via use of the American Society for Testing and Materials (ASTM) Method D6866.

In addition, the BioPreferred Programme has developed a voluntary labelling programme for the marketing of bio-based products. Under the voluntary labelling programme, bio-based products that meet the BioPreferred programme requirements carry a distinctive label for easier identification by the consumer (USDA, 2011).

Overcoming investment barriers: taxes and subsidies

In the United States, at Federal- as well as at State-level, numerous programmes have been set up to stimulate the construction of new plants (producing bio-based products) and/or new biorefineries. As part of the US Farm Bill, the Biorefinery Assistance Programme[38] provides grants and loan guarantees for the development, construction and retro-fitting of commercial-scale advanced biorefineries. The Biorefinery Assistance Programme includes funding for grants for demonstration scale plants up to 30% of costs, and loan guarantees for commercial scale plants (up to USD 250 million per plant). The programme was originally developed for advanced biofuel production such as cellulosic ethanol or butanol.

In this context, the United States Biotechnology Industry Organisation (BIO) published in 2010 an article *Bio-based chemicals and products: A new driver of US economic development and green jobs* (BIO, 2010). The report contains two important statements:

- “Bio-based products can offer significant growth to the United States economy and confer a competitive advantage in the chemicals and plastics industry. The industry can create tens of thousands of green jobs and provide a range of additional societal benefits to the United States, including a reduction in CO_2 emissions and reduced dependence on foreign oil.”

- "… to foster the growth of its bio-based products sector, federal policy should provide strong support for research, development, and commercialisation of innovative bio-based products, including grants and loans for construction of biorefineries, a strong bio-based markets programme, and tax incentives for pioneering commercial production."

In August 2012, the Qualifying Renewable Chemical Production Tax Credit Act was introduced in the Senate, a proposal to cut taxes for innovative businesses that produce renewable chemicals. This should provide renewable chemical and bio-based products access to tax credits that are available to other industries. This bill has not yet passed the House or Senate as a whole. The legislation would establish a production tax credit of USD 0.15 per pound of eligible content of renewable chemicals produced during the taxable year.

The 2008 Federal Farm Bill created the Biomass Crop Assistance Programme (BCAP),[39] a federally funded initiative that encourages the development of renewable energy sources. BCAP provides financial assistance to owners and operators of agricultural and non-industrial private forest land who wish to establish, produce, and deliver biomass feedstocks. BCAP provides two categories of assistance:

- Matching payments may be available for the delivery of eligible material to qualified biomass conversion facilities by eligible material owners. Qualified biomass conversion facilities produce heat, power, bio-based products, or advanced biofuels from biomass feedstocks;

- Establishment and annual payments may be available to certain producers who enter into contracts with the Commodity Credit Corporation (CCC) to produce eligible biomass crops on contract acres within BCAP project areas.

Value-Added Producer Grants (VAPG)[40] aim to help agricultural producers to enter into value-added activities related to the processing and/or marketing of bio-based value-added products. Generating new products, creating and expanding marketing opportunities, and increasing producer income are the end goals of this programme.

Feedstock-related policies

In the United States, the Biomass Crop Assistance Programme (BCAP), created in the 2008 Farm Bill, is a primary component of the domestic agriculture, energy and environmental strategy to reduce United States reliance on foreign oil, improve domestic energy security, reduce carbon pollution and spur rural economic development and job creation. BCAP provides incentives to farmers, ranchers and forest landowners to establish, cultivate and harvest biomass for heat, power, bio-based products and biofuels.

Box 2. Case study: Billion Ton Study (US DoE, 2011)

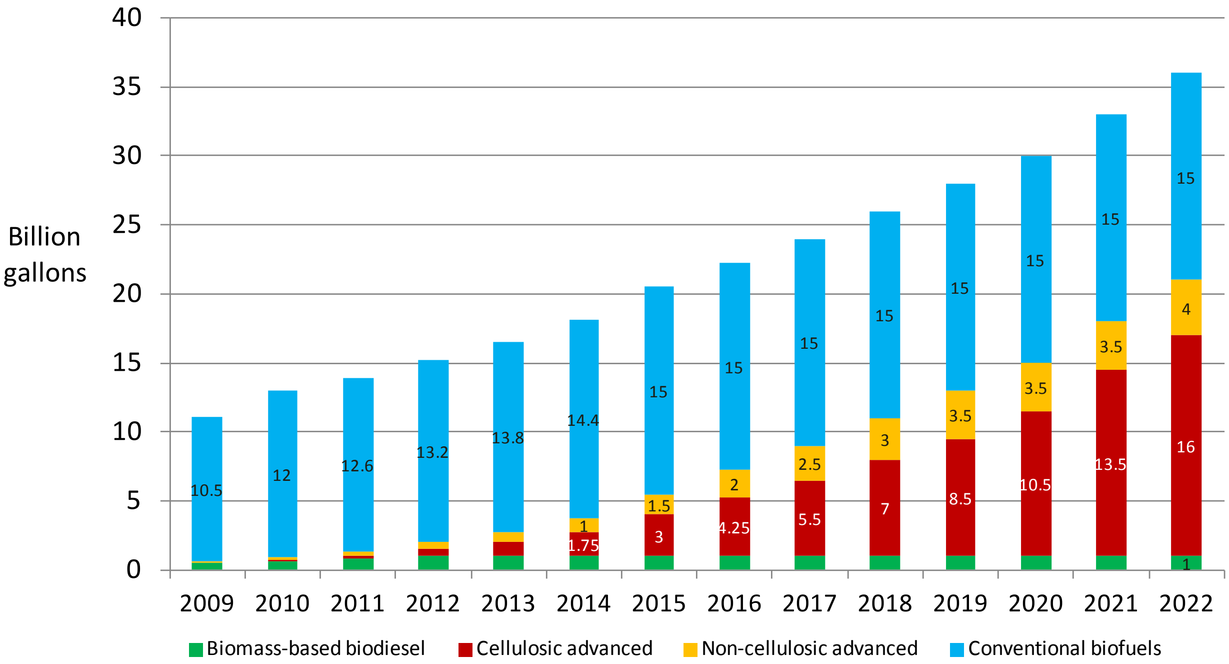
The United States Department of Energy released the "2011 US Billion Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry" report, detailing United States biomass feedstock potential nationwide. The report examines the nation's capacity to produce a billion dry tons of biomass resources annually for energy and bioproduct uses without impacting other vital United States farm and forest products, such as food, feed, and fibre crops. The study provides industry, policymakers and the agricultural community with county level data and includes analyses of current United States feedstock capacity and the potential for growth in crops and agricultural products for clean energy applications. The biomass resources identified in the report could be used to produce clean, renewable biofuels, biopower or bioproducts. For example, with continued developments in biorefinery capacity and technology, the feedstock resources identified could produce about 85 billion gallons of biofuels – enough to replace approximately 30% of the nation's current petroleum consumption. These data will be used by both the public and private sector to grow the bioenergy and bioproduct industries and help achieve President Obama's goals of dramatically expanding renewable energy resources and developing alternative fuels for America's transportation sector.

Bioenergy related policies

The United States is looking to sustainable renewable biofuels to decrease its dependence on fossil fuels and accordingly reduce GHG emissions, pollution, and waste management problems. The Energy Policy Act (EPAct) of 2005 established the first renewable fuel volume mandate in the United States. As required under the EPAct, the original Renewable Fuel Standard (RFS) programme (RFS1) required 7.5 billion gallons of renewable-fuel to be blended into gasoline by 2012.

Under the Energy Independence and Security Act (EISA) of 2007, the programme was expanded and the total amount of biofuels added to gasoline is required to increase to 36 billion US gallons by 2022 (Figure 14).

Figure 14. Biofuels production volumes mandated in RFS2



Source: OECD based on US EPA (2010). www.epa.gov/otaq/fuels/renewablefuels/regulations.htm.

The United States Environmental Protection Agency (US EPA) is responsible for developing and implementing regulations to ensure that transportation fuel sold in the United States contains a specific minimum volume of renewable fuel. The Renewable Fuel Standard (RFS)[41] programme regulations were developed in collaboration with refiners, renewable fuel producers, and many other stakeholders. To achieve the volume requirements, each year the US EPA calculates a percentage-based standard that refiners, importers and blenders of gasoline and diesel must ensure is used in transportation fuel.

European Union initiatives

Bioeconomy related policies and strategies

In 2004, the European Commission (Directorate-General Research of the European Commission) developed the concept of the Knowledge-Based Bio-Economy (KBBE). The idea behind it was that the European bioeconomy cannot compete on a global level by delivering only basic agricultural commodities.

It needs to build on European strengths (such as the ability of the science base and industry to deliver innovation in food technologies and products and in animal breeding technologies) and to have a strong chemical and manufacturing industry base. Several European Technology Platforms (ETPs)[42] have been set up and research in the area of the KBBE has been promoted and financed via the European Union's Seventh Framework Programme (FP7)[43] and via several Member State initiatives.

In February 2012, the European Union adopted a strategy and action plan, *Innovating for Sustainable Growth: a Bio-economy for Europe*, with the aim of shifting the European economy towards greater and more sustainable use of renewable resources (European Commission, 2012a). This bioeconomy strategy is part of the Europe 2020 Flagship Initiatives *Innovation Union* and *A Resource Efficient Europe* (European Commission, 2010a). The goal is to achieve a more innovative, low-emission economy, reconciling demands for sustainable agriculture and fisheries, food security, and the sustainable use of renewable biological resources for industrial purposes, while ensuring biodiversity and environmental protection. The plan therefore focuses on three key aspects:

- Developing new technologies and processes for the bioeconomy;
- Developing markets and competitiveness in bioeconomy sectors;
- Encouraging policymakers and stakeholders to work more closely together.

Some of the actions mentioned in the strategy can have direct or indirect impacts on the future development of the bioplastics market. These include:

- Strengthening coherence and synergies between European Union and national/regional programmes that support research and innovation relevant to the bioeconomy;
- Improving the accessibility to existing pilot plants and investing into additional infrastructures and activities in order to support the up-scaling of bio-based products and processes;
- Supporting knowledge acquisition and technology exchange, advisory and support services, c-ooperation and training opportunities among all actors of the supply chain and end-users, e.g. new businesses in the bio-based product market with particular attention to first users in applying sectors downstream in the value chain;
- Supporting the expansion of new markets by developing standards and standardised sustainability assessment methodologies for bio-based products and processes;
- Facilitating green procurement for bio-based products by developing labels, an initial European product information list and specific training for public procurers;
- Contributing to the development of methodological standards for bio-based products with regard to bio-based content, biodegradability and functionalities;
- Improving availability and quality of information on bioeconomy products and processes, and on their socio, economic and environmental impacts, to facilitate informed societal choices;
- Promoting zero-waste campaigns.

The *Resource-efficient Europe Flagship Initiative* (European Commission, 2011b) is part of the *Europe 2020 Strategy* (European Commission, 2010a). It supports the shift towards sustainable growth via a resource-efficient, low-carbon economy.

The *Roadmap to a Resource Efficient Europe* is one of the main building blocks of the resource efficiency flagship initiative. The Roadmap sets out a framework for the design and implementation of future actions. It also outlines the structural and technological changes needed by 2050, including milestones to be reached by 2020. The roadmap recommends an integrated approach across many policy areas, and the instruments employed are to include: legislation, market-based instruments, refocusing of funding instruments and promotion of sustainable production and consumption (European Commission, 2011c).

Some of the actions mentioned having a direct or indirect impact on the further development of the bioplastics industry and market are:

- The promotion of sustainable consumption and production by strengthening the requirements on Green Public Procurement (GPP) for products with significant environmental impacts, and by addressing the environmental footprint of products to boost the material resource efficiency of products (e.g. reusability/recoverability/recyclability, recycled content, durability), and through expanding the scope of the Ecodesign directive to non-energy related products;
- The use of recyclable/biodegradable packaging and the development of biowaste composting for the food sector;
- The focusing of the European Union Research and Innovation Framework Programme on key resource efficiency objectives, such as: the bioeconomy; recycling, re-use, substitution of environmental impacting materials; green chemistry; lower impact, biodegradable plastics;
- The shifting of taxation away from labour to environmental impacts and the reviewing of fiscal policies and instruments with a view to supporting resource efficiency more effectively, and in this context to reflect on incentives to support consumer choices and producer action in favour of resource efficiency.

Research and innovation policies

Apart from the internally-funded, in-house efforts of individual companies, bio-based products-related research in Europe is today mainly funded via public sources, at the European Union level and Member State level. Good coordination and collaboration between Member States, regional and European public programmes for research and innovation are essential for the European Union to keep pace with research and innovation programmes in other parts of the world, such as the USDA/DOE in the United States (Clever Consult, 2010).

European framework programmes for research and innovation

Since 1983 there have been seven European Union Framework Programmes (FPs) supporting research and development and one Competitiveness and Innovation Programme (CIP), running from 2007 to 2013, that focused on innovation, primarily in SMEs. *Horizon 2020* will be the new European financial instrument supporting research and innovation and implementing the *Innovation Union* initiative, a Europe 2020 flagship initiative aimed at securing Europe's global competitiveness. It will run from 2014 to 2020 and has a proposed total budget of EUR 80 billion. Another aim of *Horizon 2020* is to tackle societal challenges by helping to bridge the gap between research and the market by, for example, helping innovative enterprises to develop technological breakthroughs into viable products with real commercial potential. This market-driven approach will include the creation of partnerships between the private sector and Member States to assemble the necessary resources (European Commission, 2011a).

Several European Union Member States aim to co-ordinate their research via the ERA-NET[44] scheme (e.g. the ERA-NET for Industrial Biotechnology). Under the ERA-NET scheme, national and regional authorities identify the research areas of common interest and launch collaborations via joint calls for projects.

In Europe, the BIOCHEM[45] project has been launched to develop tools, processes and information to support companies, especially start-ups and small and medium sized enterprises (SMEs), to overcome the barriers to market entry in this sector and develop a successful sustainable business in bio-based products. BIOCHEM is working to improve the innovation capacity of bio-based chemistry start-ups and SMEs via market information, audits, coaching and entrepreneurial teaching classes, business planning tools, a European online partnering and innovation resources system, and a funding directory specifically intended for bio-based SMEs. The project is part of the European Commission's INNOVA programme (financed by the CIP) and operates as an Eco-Innovation Platform. The project was launched in February 2010, will last three years, and involves seventeen partner organisations from seven European countries.

Public private partnerships (PPPs) for the bio-based industries

The European Commission is currently investigating the development of a number of PPPs in the form of Joint Technology Initiatives or JTIs. One of the proposals is for a PPP on bio-based industries (BRIDGE: Bio-based and Renewable Industries for Development and Growth in Europe). BRIDGE focuses on developing European Union-based value chains and accelerating the transition to advanced feedstock for biorefineries.

Specifically, it will focus on:

- Building new value chains based on the development of sustainable biomass collection and supply systems with increased productivity, and improved utilisation of biomass feedstock (including co- and by-products), while unlocking utilisation and valorisation of waste and lignocellulosic biomass;
- Bringing existing value chains to new levels, through optimised uses of feedstock and industrial side-streams, and offering innovative added-value products to the market, thus creating a market-pull and reinforcing the competitiveness of European Union agriculture and forest based industries;
- Bringing technology to maturity through research and innovation, and through upgrading and building demonstration and flagship biorefineries that will process the biomass into a range of innovative bio-based products.

The European Commission would invest almost EUR 1 billion while industrial partners have made a commitment to invest over EUR 2.8 billion in research and innovation efforts between 2014 and 2020 as a contribution to this initiative. The final budget will depend on the outcome of the Multiannual Financing Framework negotiations (MFF).

Policies to stimulate demand

Lead Market Initiative

The European Commission's Lead Market Initiative (LMI) for bio-based products is a synchronised approach to stimulating demand for bio-based products (European Commission, 2007). In 2008, the Commission established an expert group composed of representatives from national governments, industry and academia, the *Ad-hoc Advisory Group for Bio-based Products*. It analysed the impact of existing legislation and policies on products made from renewable raw material. The analysis focused on all the different steps in the production and supply chain, including:

- Supply of renewable raw materials;
- Production of intermediate chemicals, materials and components;

- Manufacture of assembled products;
- Retail market conditions;
- Use of bio-based products;
- Disposal of bio-based products as waste, through re-use, recycling, recovery or other options.

At the end of 2009, the Ad-hoc Advisory Group agreed on measures that make use of four LMI demand-side instruments, namely: regulation, public procurement, standardisation and complementary measures. Standardisation, for example, involves the development of industry standards that set-out the environmental and other credentials of bio-based products, with the aim of improving market conditions, facilitating public procurement and enhancing public understanding and awareness.

Numerous recommendations of the Ad-hoc Advisory Group remain to be implemented, but progress has been made in the areas of public procurement and standards. Standards and their use are perceived as key to the removal of barriers to the uptake of bio-based products in downstream industrial, consumer and public procurement markets, and progress involves the development of industry standards, the development of a common methodology for Life Cycle Assessment, better labelling and the improved provision of information to consumers, and the development of a methodology for providing information about the sustainability of biomass production (CSES, 2011).

In terms of aligning LMI activities with policies in Member States, progress has been made on a number of fronts in a small but growing number of countries. For example, there has been co-ordination between the German Ministry of Research and the LMI in the frame of the 'Bio-Economy Council' initiative, and discussions on how to take actions forward for the sector have taken place with the German Ministry of Economic Affairs and the German Ministry of Agriculture. Co-operation has been fostered with the French government, and the Belgian government has recently expressed an interest. The Dutch Ministry of Economic Affairs, Agriculture and Innovation has developed a clear policy towards the Bioeconomy, and the Italian government has been active with regard to the building of pilot and demonstration biorefinery plants.

Box 3. The European Union Advisory Group's main recommendations to promote bio-based products (Ad-hoc Advisory Group for Bio-based Products, 2009)

Legislation promoting market development

- The biological/bio-based carbon contained in bio-based products shall be deducted in the calculation of the total CO_2 equivalent emissions of the products;
- Consider setting indicative or binding targets for certain bio-based product categories, drawing on the experience from biofuel quotas in the EU;
- Allow Member States to reduce taxes for sustainable bio-based product categories.

Product-specific legislation

- Allow bio-based plastic to enter all waste collection and recovery systems, including composting, recycling and energetic recovery (depending on the type of plastic and compliance with applicable standards); Bio-based plastics certified compostable according to EN 13432 should gain unhindered access to biowaste collection;
- Study the possibility of mandating the use of biolubricants and hydraulic fluids in environmentally sensitive areas. This could be implemented e.g. via soil protection and water protection legislation;
- Bio-based construction materials (foams for insulation, composite material, mortar, and concrete made of vegetative aggregate particles) have now become sufficiently advanced to offer a real alternative. The Construction Products Directive should promote the specificities of bio-based products. In addition, new and transparent standards showing the product capabilities are needed to help demonstrate that bio-based materials comply with construction legislation.

Legislation related to biomass

- Legislation and policies must allow renewable raw materials for industrial use to be available in sufficient quantity of good and guaranteed quality and at competitive price;
- Increase investments in developing and optimising infrastructures and logistics for an optimal use of all available biomass (including waste).

Encourage Green Public Procurement for bio-based products

- Encourage contracting authorities in all EU Member States to give preference to bio-based products in tender specifications. A requirement or a recommendation to give preference can be laid down in a national action plan adopted by the government. Preference should be given to bio-based products unless the products are not readily available on the market, the products are available only at excessive cost, or the products do not have an acceptable performance.

Standards, labels and certification

- Develop clear and unambiguous European and international standards. The standards will help to verify claims about bio-based products in the future (e.g. biodegradability, bio-based content, renewable carbon, recyclability, and sustainability);
- The sustainability assessment should be based on all three pillars of sustainability: environmental, social and economic. While we need (to develop) tools to assess sustainability of products, we need to ensure the tools used will stimulate and not limit the development and implementation of bio-based products;
- Begin a reflection process on what types of specific product labels are suitable for bio-based products and what information to be given to the consumer.

Financing and funding of research

- Continue to stimulate and enhance technological innovation and the development of technology: setting up demonstration projects via public-private partnerships.

Green Public Procurement (GPP)

Launched in 2008, GPP is a voluntary policy instrument (under Directorate-General Environment of the European Commission) that provides guidelines that aim to inform National Action Plans (European Commission, 2008a). Member States and public authorities determine their own implementation targets for the purchase of sustainable products. This has resulted in varying responses from Member States, with some countries setting ambitious 100% targets for green procurement (by 2010 in the case of the Netherlands).

The potential for increasing demand for bio-based products through public procurement is huge, as European public authorities spend almost EUR 2 000 billion, or 16% of GDP, on goods and services yearly. Almost all product areas could potentially feature products made entirely or partly from renewable raw material. Likewise, the production of almost all types of services could potentially benefit from bio-based inputs. The *Green Public Procurement Guidelines* now include criteria that allow bio-based products to be given preference in tender specifications.

By integrating the requirement for bio-based content with other common GPP criteria, and by applying the European Union Ecolabel to products complying with the minimum level of bio-based content set for a particular product category, public procurers are able to distinguish products that are eligible for preferential selection.

Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom have adopted National GPP Action Plans or equivalent strategies, and others are in the process of preparing strategies for future adoption (European Commission, 2012b).

Standards and legislation

Packaging and packaging waste

The Council Directive 94/62/EC (1994) on Packaging and Packaging Waste (European Commission, 1994) aimed to harmonise national measures in Europe in order to prevent or reduce the impact of packaging and packaging waste on the environment. It contains provisions on the prevention of packaging waste, on the re-use of packaging and on the recovery and recycling of packaging waste. Although the European Commission asked the European Committee for Standardisation (CEN), via Mandate M200, to develop the harmonised standard EN 13432 concerning *Requirements for Packaging Recoverable through Composting and Biodegradation*, compliance with this standard is not mandatory for producers intent on labelling their products as “biodegradable” or “organically recyclable”. A possible review of the Packaging and Packaging Waste Directive is currently being discussed.

The European Commission is working on a Green Paper on Plastic Waste which could propose an EU-wide ban on plastic bags, pricing measures designed to reduce plastic bag use, or the increased use of recycled plastics and bioplastics through phased targets. The implementation of such targets would need to be associated with supporting measures to raise awareness concerning the potential use of bioplastics/recycled materials and their treatment at end-of-life by consumers.

Composting and biowaste

At present, very few European Union Member States have nationwide industrial composting systems in place. In the Netherlands, EN 13432 certified packaging is allowed to enter the composting system. Although some European Union Member States (for example, Belgium, Denmark, Finland, Germany, Italy and Sweden) have existing composting infrastructure, there is no clear policy support for the composting of biodegradable and compostable products. In 2008, the European Commission presented a Green Paper on the management of bio-waste in the European Union that demonstrated the need for several measures and opened up a debate on the topic. In 2009, after an impact assessment, the European Commission published its *Communication on Future Steps in Bio-waste Management in the European Union.* In this, a series of measures to be implemented at European and national levels were foreseen. Since then, work by the Joint Research Centre (JRC)[46] has started to identify end-of-life criteria for biodegradable waste (European Commission, 2008b).

The European Union Lead Market Initiative recommends allowing "bio-based plastic to enter all waste collection and recovery systems, including composting, recycling, and energetic recovery – depending on the type of plastic". It also recommends that "bio-based plastics, certified compostable according to EN 13432, should gain unhindered access to biowaste collection" (European Union Ad-hoc Advisory Group for Bio-based Products, 2009). Work leading to the future implementation of these recommendations has either been completed (see the CEN publications CEN/TS 16137: *Biopolymers - Determination of bio-based carbon content* and FprCEN/TS 16295: *Biopolymers - Declaration of the bio-based carbon content*) or is currently underway (e.g. work on terminology, methods, sustainability criteria, life-cycle analyses and certification that is scheduled to lead to the production of CEN TC 411 in the coming years).

Feedstock-related policies

The Common Agricultural Policy (CAP)

The Common Agricultural Policy (CAP) is a system of European Union agricultural subsidies and programmes that accounts for almost half of the budget of the European Union. The aim of the CAP is to ensure that farmers have a reasonable standard of living, to provide consumers with quality food at fair prices and to preserve rural heritage. The CAP is the most important feedstock-related policy in Europe, having an impact on availability and price of feedstock for food and industrial (non-food) use. The original CAP combined a direct subsidy payment for crops and land which could be cultivated with price support mechanisms, including guaranteed minimum prices, import tariffs and quotas on certain goods from outside the European Union.

Specific support for energy crops and bioenergy, but not for bio-based materials

Since 2004, an energy crop support of EUR 45/ha has been available in the European Union 15 countries for the production of energy crops on basic land (with a maximum of 1.5 million ha). The system was extended to the new Member States in 2007, with an increase of the maximum area to 2 million ha. Initially, the response to this premium from agriculture was lower than expected, probably due to the fairly low premium offered and the bureaucratic burden associated with receiving it. After a few years, however, the energy crop premium started to meet with greater success. By 2007, the maximum area was reached, and practically no energy crops were grown without this support (BACAS, 2011).

Recent reforms of the current CAP have reduced import controls and related subsidies to land stewardship rather than to specific crop production. In its "Health Check" of the CAP, the European Commission abolished the energy crop premium and the compulsory set-aside. No specific support for bioenergy production thus remains in the CAP. It was assumed that biomass production for energy would be stimulated by strong demand due to the existence of policy targets for biofuels (European Commission, 2010c).

The new CAP (2014-2020)

The European Commission, the European Parliament and the Member States are currently discussing the new CAP for the coming years (European Commission, 2010b). In the proposal of the Commission, support for science and innovation is a key element, as is the notion that support for the bioeconomy (and not only bioenergy or biofuels) should be an objective of rural development policy. Another key objective of the new CAP proposal is the greening of agriculture through the introduction of incentives for sustainable farming practices. Following a debate in the European Parliament and the Council, approval of the different regulations and implementation schemes is expected by the end of 2013, with a view to having the CAP reform in place as from 1 January 2014.

The sugar regime within the CAP

The European Union sugar regime covering the production and marketing of beet and sugar cane within EU member countries was introduced as part of the CAP in 1968. Sugar is a major feedstock for the production of bio-based materials (such as bioplastics) via fermentation processes. The regime is based on three key elements. Firstly, it guarantees minimum prices to sugar producers. Secondly, high tariff barriers aim to keep foreign competitors out of the European Union marketplace. Thirdly, between 2 and 3 million tonnes of surplus European sugar each year are disposed of on world markets at heavily subsidised prices. In the past, the guaranteed minimum price for European Union sugar made it three or four times more expensive than world market prices (BACAS, 2011).

In 2006, the European Union decided to reduce the guaranteed price of sugar by 36% over four years. According to the European Union, this was the first serious reform of sugar under the CAP for 40 years. Although the aim was to lower the minimum guaranteed price for sugar drastically over the period 2006-2010, in anticipation of the envisaged free global market for sugar, this price cut was applied only to sugar used in the food industry, which accounts for the bulk of EU sugar, but not to industrial sugar, which represents about 3% of the total (BACAS, 2011).

As part of the new CAP, the European Commission has recently proposed to abolish the production quotas for sugar by October 2015, with potentially beneficial consequences for European bioplastics producers, though organisations such as the European Committee of Sugar Manufacturers (CEFS) and the International Federation of European Beet growers (CIBE) are calling for the quota system to be extended to 2020.[47]

Bioenergy related policies

Worldwide, many governments support their emerging biofuel industries via subsidies, mandates, adjustments to fuel taxes and incentives for the use of flexible-fuel vehicles. Within the European Union, legislation and policy on bioenergy and biofuels are determined at both European Union and Member State levels, with many links between the policies and instruments developed at these levels.

The first European Union biofuel directive aimed for a 2% share of renewables in the European Union energy mix, to be achieved by the end of 2005, with a 5.75% share targeted by the end of 2010 (European Commission, 2003a). A second directive declared biofuels to be exempt from the tax on mineral oil products (European Commission, 2003b).

The Renewable Energy Directive of 2009 set a 20% share of renewable energies in the European Union energy mix by 2020 as a mandatory target. By the same date, each Member State must also ensure that 10% of the energy requirements of all terrestrial transport (such as road transport and train fuel) derive from renewable energy, defined to include biofuels and biogas, as well as hydrogen and electricity. In addition, to stimulate the use of second generation biofuels, biofuels from waste, residues, non-food cellulosic material and lignocellulosic material will count twice towards achieving the renewable energy transport target. Although the overall 20% renewable energy target to be achieved by 2020 will require a rapid deployment of solid biomass applications for heat and electricity, every European Member State has agreed to implement the Renewable Energy Directive (European Commission, 2009).

CONCLUSIONS AND FUTURE WORK

Summary of policy trends

Policies directly targeting bioplastics

There are very few policies dedicated to bioplastics around the globe, just as there are few specifically dealing with bio-based chemicals and other materials. Moreover, when policies in different countries are reviewed, it is apparent that bioplastics are at a relative disadvantage compared to biofuels. As a point of reference, in 2009 the Renewable Energy Policy Network for the 21st Century reported that 73 countries had bioenergy targets (RENI21, 2009), whereas very few countries have similar targets for bioplastics.

Within individual countries, e.g. the United States (Steenblik, 2007), support policies for biofuels can be found at various points along value chains that stretch from farms, where the biomass is grown, to the manufacture and end-of-life options for final products, but this is rarely the case for bioplastics.

Of all the United States federal funding for research and development in biomass and bioenergy since the 1970s, as much as 70% has gone to biofuels (Waltz, 2008).

Some of the reasons why large differences exist are clear enough:

- Demand – The profit margins on chemical production tend to be larger than those for fuels, but the demand for fuel is so massive that the fuels market dwarfs that for chemicals. In particular, the volumes of liquid biofuels in mass markets are vast in comparison to those for bioplastics. The prospect of capturing just a tiny percentage of the market for fuels is thus a huge incentive for small biofuel companies and investors.
- Regulation – the markets for chemicals and bioplastics are highly regulated and thus have high entry costs. Fuels are used once (burned), whereas many chemicals and bioplastics are exposed to humans along longer value chains, thus incurring greater concerns relating to safety and toxicity.
- Product specifications – specifications for fuels are relatively simple. For plastics, however, consumer acceptance criteria are harder to achieve and predict, thus requiring manufacturers to demonstrate greater product sophistication. Customers expect a range of properties from different plastics in different applications e.g. brittleness, elasticity, freeze tolerance and heat resistance.

The only bioplastics-related policies that are commonly found across a range of countries are those concerned with the use of biodegradable plastic bags, especially shopping bags.

Infrastructure and capacity building

A small number of countries are actively developing a manufacturing capacity for bioplastics:

- Best placed in terms of the relative cost and availability of sustainable biomass is Brazil, where new manufacturing plants for bio-based thermoplastics are coming on-stream. This is in large part due to a long history of policy support for the manufacturing of bioethanol as a biofuel. This gave Brazilian companies the know-how and the confidence to work on bio-based plastics derived from bioethanol.
- After banning the distribution of traditional plastic bags, Italy – which has a large composting infrastructure compared to most other European countries – is building capacity in biodegradable

polyesters and shopping bags. Another significant development is the conversion of fossil-based chemical production facilities to bio-based.

- The United States, where much of the original innovation in bioplastics was carried out, has seen large-scale public and private investments into integrated biorefineries. With companies already producing bioplastics, integrated biorefining is a significant infrastructure development in that it envisages the production of biofuels and other bio-based products at these sites. The United States has supported not only fundamental research and development, but also scale up to pilot and demonstration plants.
- Through the Biomass Nippon Strategy, Japan has a blend of production-oriented initiatives, significant consumption targets and a well-developed certification programme to demonstrate the environmental benefits and safety of bioplastics. Japan has also been strong in terms of research and development. However, sourcing of biomass is an issue given land resource constraints in Japan.
- The Thai government has declared bioplastics to be one of its strategic industries and has developed and implemented a diverse set of policies spanning, for example, research and development support, biomass supply support, and tax and import duty incentives, with the result that several production plants are being built by domestic and international companies.

Public procurement

Realising that the potential for stimulating demand through public procurement is vast, the United States has developed and implemented the most advanced public procurement programme for bio-based products (the United States Department of Agriculture BioPreferred programme). The potential of public procurement has also been realised in the EU, where public authorities spend 16% of GDP on publicly procured goods and services annually. Consequently, the European Union *Green Public Procurement Guidelines* now include criteria that allow bio-based products to be given preference in tender specifications.

Bioeconomy related policy

Both the United States and the European Union have unveiled significant bioeconomy strategies, and the list of other countries producing their own bioeconomy strategies is growing. Because so many countries are involved in the European Union, the European Union Bioeconomy Strategy and Action Plan could stimulate policy actions directly targeting bioplastics along a broad front. A crucial step in Europe could be measures aimed at the development, perhaps via public-private partnerships, of essential scale-up facilities and demonstrator plants.

Key messages

The key points of this report are as follows:

- Bioplastics have a role to play in the bioeconomy due to their potential to address environmental and economic challenges. Each bioplastic has to be examined on a case-by-case basis, but greenhouse gas (GHG) emissions savings look promising relative to the emissions associated with petro-plastics. Projections also indicate that bioplastics have the potential to generate greater numbers of jobs than biofuels.

- New bioplastics are being developed, displacing plastics derived from petrochemicals, and new applications are emerging (through improvements in existing bioplastics and the development of new ones). Bio-based equivalents of the major thermoplastics that can compete in the same product markets and enjoy the same end-of-life options as the petro-based thermoplastics have been developed. In particular, very recently, there has been uptake of bio-based PET for carbonated drink containers that is changing the dynamics of the bioplastics market.

- Countries are acting individually and collectively to develop the bioeconomy and reap the anticipated benefits, though efforts to support the specific development of bioplastics are less common. Generally, biofuels policy support is much greater than it is for either bio-based plastics or bio-based chemicals. This is likely to make the development of the bioeconomy uneven, and may disfavour the use of biomass for bioplastics and bio-based chemicals. It may also constrain the development and operation of integrated biorefineries.

- Standards and certification schemes relating to sustainability offer a way of differentiating bio-based from petro-based plastics in the market place. However, measuring sustainability remains a difficult task, with no one measurement tool suitable for the task even though many sustainability frameworks have been developed, often related to forestry and bioenergy applications.

- Lack of adequate and harmonised definitions of sustainability and internationally accepted sustainability assessment methodologies could complicate the trading of biomass and bio-based products internationally, with products deemed sustainable in one country not accepted as such in others.

Future work

The OECD Working Party on Biotechnology is now embarking on an examination of policy options for governments in the area of bio-based chemicals including bioplastics. The objectives are to:

- Continue to review current policies for bio-based chemicals and plastics, their roles and impacts, in the context of policies supporting the other main use of biomass e.g. biofuels.

- Identify where policy can impact the bio-based production value chain in a cost-effective manner, including an examination of the role of public-private partnerships.

- Identify policy options for governments in the area of bio-based chemicals and bioplastics.

ANNEX I – LIST OF ABBREVIATIONS

PE: Polyethylene

PP: Polypropylene

PHA: Polyhydroxyalkanotes – for example, poly-β-hydroxybuturate (PHB), the first of the biodegradable plastics made through a fermentation process

PET: Polyethylene terephthalate - a polyester thermoplastic used in synthetic fibres and plastic bottle production

PBS: Polybutylene succinate - poly(butylene succinate) (PBS) synthesised from succinic acid and 1,4-butanediol (BDO). PBS and its related polymers are a family of biodegradable plastics with excellent biodegradability and balanced mechanical properties

PCL: Polycaprolactone (PCL) is a biodegradable polyester produced by chemical synthesis, not through fermentation

PBAT: Poly(butylene adipate-co-terephthalate) – a starch-based biodegradable composite, typically used in plastic films

PLA: Polylactic acid – a polyester thermoplastic derived from renewable resources, such as corn starch

PTT: Polytrimethyl terephthalate – a resin which contains up to about one-third of renewably sourced content for packaging applications

ANNEX II – LIST OF BIODEGRADATION AND COMPOSTING STANDARDS

Standard	Description
ASTM D6954 – 04	Standard guide for exposing and testing plastics that degrade in the environment by a combination of oxidation and biodegradation
AS 4736 – 2006	Biodegradable plastics – biodegradable plastic suitable for composting and other microbial treatment
ASTM D5209 – 92	Standard test method for determining the aerobic biodegradation of plastic materials in the presence of municipal sewage sludge
ASTM D5338 – 98	Standard test method for determining aerobic biodegradation of plastic materials under controlled composting conditions
ASTM D5526 – 94	Standard test method for determining anaerobic biodegradation of plastic materials under accelerated landfill conditions
ASTM D5951 – 96	Standard practice for preparing residual solids obtained after 2002 biodegradability standard methods for plastics in solid waste for toxicity and compost quality testing
ASTM D5988 – 03	Standard test method for determining aerobic biodegradation in soil of plastic materials or residual plastic material after composting
ASTM D6002 – 96	Standard guide for assessing the compostability of environmentally degradable plastics
ASTM D6340 – 98	Standard test methods for determining aerobic biodegradation of radio-labelled plastic materials in an aqueous or compost environment
ASTM D6400 – 99	Standard specifications for compostable plastics
ASTM D6691 – 01	Standard test method for determining aerobic biodegradation of plastic materials in the marine environment by a defined microbial consortium
ASTM D6692 – 01	Standard test method for determining biodegradability of radio-labelled polymeric plastic materials in seawater
ASTM D7081 – 05	Standard specifications for non-floating biodegradable plastics in the marine environment
DIN V 54900-2	Testing of compostability of plastics – Part 2: testing of the complete biodegradability of plastics in laboratory tests
EN 13432:2000	Requirements for packaging recoverable through composting and biodegradation – test scheme and evaluation criteria for the final acceptance of packaging
EN 14045:2003	Packaging – evaluation of the disintegration of packaging materials in practical oriented tests under defined composting conditions
EN 14046:2003	Packaging – evaluation of the ultimate aerobic biodegradability of packaging materials under controlled composting conditions – method by analysis of released carbon dioxide
EN 14047:2002	Packaging – determination of the ultimate aerobic biodegradability of packaging materials in an aqueous medium –method by analysis of evolved carbon dioxide
EN 14048:2002	Packaging – determination of the ultimate aerobic biodegradability of packaging materials in an aqueous medium–method by measuring the oxygen demand in a closed respirometer
EN 14806:2005	Packaging – preliminary evaluation of the disintegration of packaging materials under simulated composting conditions in a laboratory-scale test
ISO 14851:1999	Determination of the ultimate aerobic biodegradability of plastic materials in an aqueous medium – method by measuring the oxygen demand in a closed respirometer

ISO 14852:1999	Determination of the ultimate aerobic biodegradability of plastic materials in an aqueous medium – method by analysis of evolved carbon dioxide
ISO 14855:1999	Determination of the ultimate aerobic biodegradability and disintegration of plastic materials under controlled composting conditions – method by analysis of evolved carbon dioxide
ISO 14593:1999	Water quality – evaluation of the ultimate aerobic biodegradability of organic compounds in aqueous medium – method by analysis of inorganic carbon in sealed vessels (CO2 headspace test)
ISO 15314:2004	Methods for marine exposure ISO 16221:2001 Water-quality – guidance for the determination of biodegradability in the marine environment
ISO 16929:2002	Plastics – determination of the degree of disintegration of plastic materials under defined composting conditions in a pilot-scale test
ISO 17556:2003	Plastics – determination of the ultimate aerobic biodegradability in soil by measuring the oxygen demand in a respirometer or the amount of carbon dioxide evolved
ISO 20200:2004	Plastics – determination of the degree of disintegration of plastic materials under simulated composting conditions in a laboratory-scale test
CEN/TR 15822	Plastics – biodegradable plastics in or on soil – recovery, disposal and (under approval) related environmental issues
AFNOR NF U52-001	Biodegradable materials for use in agriculture and horticulture-mulching products - Requirements and test methods

NOTES

1 http://ec.europa.eu/research/bioeconomy/pdf/201202_innovating_sustainable_growth.pdf

2 www.whitehouse.gov/sites/default/files/microsites/ostp/national_bioeconomy_blueprint_april_2012.pdf

3 http://plastics.americanchemistry.com/Life-Cycle

4 Our Common Future (1987), www.un-documents.net/our-common-future.pdf

5 http://stats.oecd.org/glossary/detail.asp?ID=2625

6 www.oecd.org/chemicalsafety/testingofchemicals/34898616.pdf

7 www.epa.gov/compost/basic.htm

8 www.nnfcc.co.uk/publications/nnfcc-crop-factsheet-miscanthus

9 www.sciencedaily.com/releases/2009/11/091123125201.htm

10 Direct emissions can be from a land use change which is a conversion of land previously unused (e.g. unmanaged forest) to cropland, or between two different crop types. The tillage of unmanaged land exposes large amounts of soil organic carbon to the atmosphere, with the concomitant production of relatively huge amounts of CO_2. Paying back this CO_2 debt can take long time periods.

11 Indirect emissions can be from a land use change which occurs when land for an existing activity (e.g. food or timber production) is converted to grow bioenergy feedstock or when a food crop is used for bioenergy (e.g. diversion of maize for ethanol production).

12 http://en.european-bioplastics.org/blog/2012/10/10/pr-bioplastics-market-20121010/

13 www.bio-based.eu/market_study/media/files/13-03-26MarketStudyLeaflet.pdf

14 Material that is subject to putrefaction.

15 Note: there is a list of abbreviations in the Annex.

16 www.sustainlabour.org/

17 www.ecolabelindex.com/

18 http://projects.wri.org/sd-pams-database/argentina/biofuels-act-26-093

19 http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Buenos%20Aires_Argentina_7-6-2012.pdf

20 www.pac.gov.br/sobre-o-pac

21 www.ipt.br/EN

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[34] www.be-basic.org

[35] www.indbiotech.no

[36] United States Department of Agriculture

[37] www.biopreferred.gov/

[38] www.rurdev.usda.gov/energy.html

[39] www.fsa.usda.gov/FSA/webapp?area=home&subject=ener&topic=bcap

[40] www.rurdev.usda.gov/BCP_VAPG.html

[41] www.fas.org/sgp/crs/misc/R40155.pdf

[42] http://cordis.europa.eu/technology-platforms/home_en.html

[43] http://cordis.europa.eu/fp7/home_en.html

[44] www.era-ib.net

[45] www.biochem-project.eu

[46] http://ec.europa.eu/dgs/jrc/index.cfm

[47] Alan Matthews, http://capreform.eu/the-political-economy-of-eliminating-sugar-quotas-in-2015/

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