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Biobased plastics in a bioeconomy

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Bioeconomy plans include a biobased industries sector in which some oil-derived plastics and chemicals are replaced by new or equivalent products derived, at least partially, from biomass. Some of these biobased products are here today, but to fulfil their societal potential, greater attention is required to promote awareness, and to improve their market share while making valuable contributions to climate change mitigation.

Plastics, an industrial and societal revolution

Modern plastics should be hailed by society as a huge success. And yet, no material on Earth has been so highly revered for its usefulness, but so maligned by society, as plastic [1]. Plastics are uniquely flexible materials that have seen them occupy a huge range of applications, from simple packaging to complex engineering. Plastics production worldwide has surpassed steel and continues to grow. Twenty times more plastic is produced today than 50 years ago [2].

Environmental problems

The plastics revolution has come at a price. The durability of plastics was originally viewed as a virtue; this durability has created environmental vices, and led to the early research and development of the first biodegradable plastics. With climate change as a societal grand challenge, a return to durable, biobased plastics is also seen as virtuous due to their biobased carbon content.

The landfill dilemma

During the 1980s increasing amounts of municipal solid waste (MSW) emerged as a potential crisis in many areas of the United States because of shrinking landfill capacity, rising costs, and strong public opposition to new solid waste facility sitings [3]. In 1960 plastics accounted for about 0.5% of American MSW generation. By 2010 this had risen to 12.4% [4]. A large proportion of plastics in modern use are for single-use applications, and in many countries the end-of-life of these has historically been disposal to landfill. The total recalcitrance of fossil-derived plastics to biodegradation means that these plastics, many of which are light but bulky, end up occupying huge volumes of landfill space in a world of dwindling numbers of suitable new landfill sites.

Oceanic garbage patches

There has been a growing awareness of the accumulation of large quantities of plastic wastes in certain ocean locations, for example, in the North Atlantic Gyre, and the Northern Pacific Gyre 'eastern garbage patch'. In a long-term study in the North Atlantic, one seawater sample contained the equivalent of 580 000 pieces of plastic per square kilometre [5]. The total amount of plastic entering the marine environment is unknown, but is of the order of millions of tonnes per annum.

Blots on the horizon?

Competition for crude oil production and energy security

The unparalleled success of plastics as a material shows no signs of abatement. Overall plastics consumption could grow from the current 250 000 kilotonnes per year to about 1 million kilotonnes by the end of this century. In the absence of huge new inexpensive crude oil discoveries, such an expansion in plastics consumption is unsustainable. It might be expected that crude oil will become more expensive and the supply more volatile, thereby further threatening society on several fronts.

Climate change

The Intergovernmental Panel on Climate Change (IPCC) trajectory to 2050 for stabilisation of atmospheric green house gas (GHG) concentrations at 450 ppm CO_2 requires emissions reduction of 80% compared to the 1990 level [6]. This will be perhaps the biggest human challenge of the next generation. The vast majority of plastics in current production are derived from crude oil, thus, their GHG emissions are of concern.

A central role for biobased plastics in a future bioeconomy?

Biodegradable and biobased plastics as substitutes for petroplastics may be part of the solution in the struggle with climate change. However, estimates of GHG emissions savings from production of various bioplastics and biobased chemicals vary widely (Figure 1); an unhelpful situation for the industry. This situation should be a target for policy action, specifically regarding the methods for making the calculations, which is largely performed by life cycle analysis (LCA).

There has been a significant shift in the market for biobased plastics from the earliest ones, which were designed to be biodegradable, to more durable, but nonbiodegradable, substitutes for the fossil-derived thermoplastics

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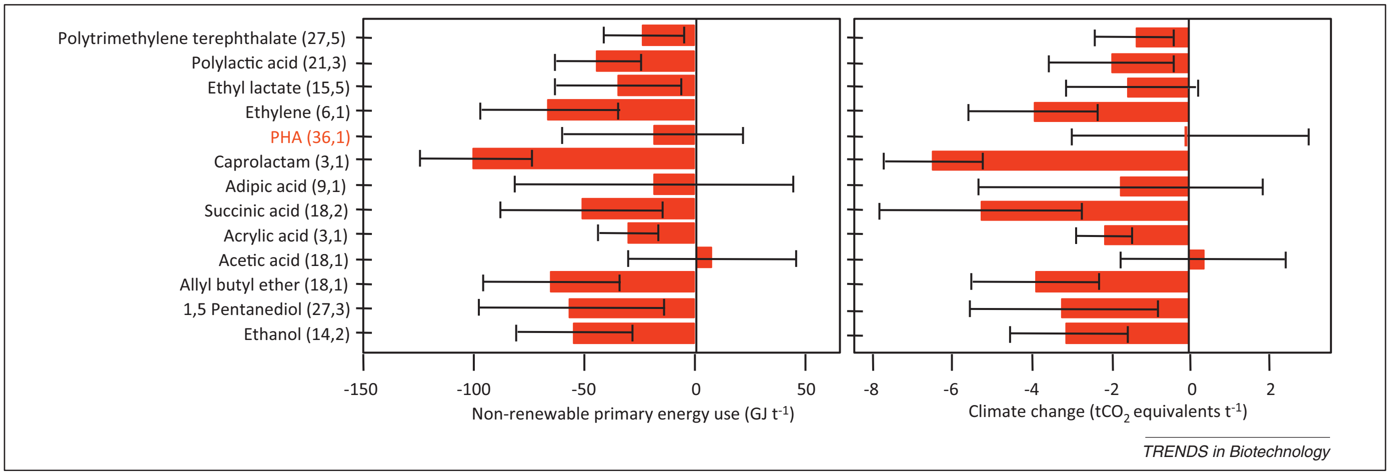

Figure 1. Average nonrenewable primary energy use and greenhouse gas emissions of biobased chemicals in comparison to conventional chemicals (adapted from [11]). Although the figures themselves are encouraging, the large error bars point to a problem of a lack of standardisation of life cycle analysis. Such uncertainties in the data undermine their value, and potentially harm the biobased industries.

produced in massive volumes, especially polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET). A recent forecast (http://en.european-bioplastics.org/blog/2012/10/10/pr-bioplastics-market20121010/) predicts that the worldwide production capacity for bioplastics will increase from around 1.2 million tonnes in 2011 to approximately 5.8 million tonnes by 2016. By far the strongest growth will be in the biobased, nonbiodegradable bioplastics described above. Perfecting these in biobased forms dramatically increases the uses of, and markets for, biobased plastics. Theoretically their GHG emissions should be significantly lower than their petro-equivalents, a theory that needs to be tested on a case-by-case basis. Some or all of the carbon in the bioequivalents is derived from atmospheric CO_2 fixed during the growth of the plants used as biomass, and therefore they are closer to carbon neutrality than the petro-equivalents when their carbon is returned to the atmosphere as CO_2.

As bio-PE, bio-PP, bio-PET, and in the future bio-PVC, are identical molecules to the petro-equivalents, their performance characteristics should also be identical. Moreover, this opens up other end-of-life options for the biobased thermoplastics. There is no impediment for them to enter the existing plastics recycling infrastructure, whereas other bioplastics such as polylactic acid cannot readily do this. In some countries, incineration with energy recovery is an attractive end-of-life option with the added environmental advantage of electricity generation from waste. When cradle-to-grave LCA is performed, the end-of-life efficiency is vital to assigning the overall environmental performance of a plastic.

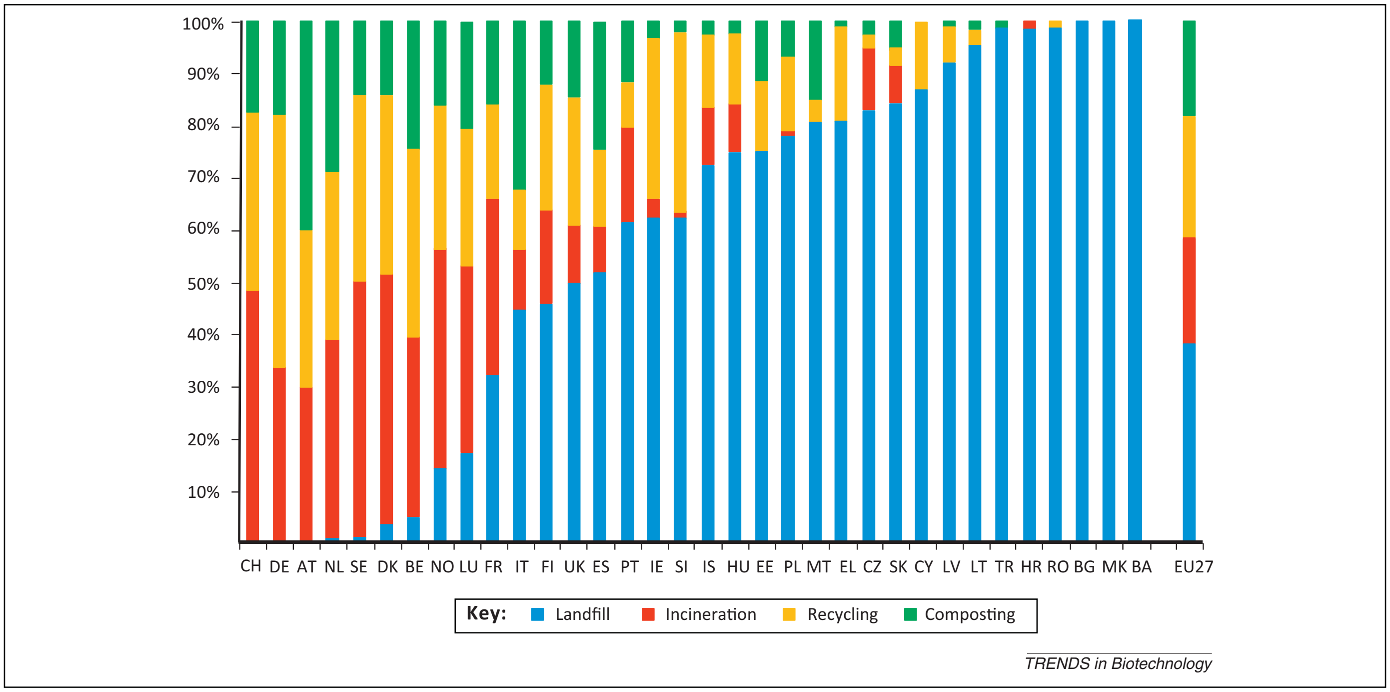

Figure 2. Municipal waste treatment, Europe 2009 (http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Municipal_waste_statistics). The huge diversity across Europe makes policy particularly challenging.

Industrial-scale composting of biodegradable plastics is possible in only a few countries (Figure 2). In Europe, even in those that have the infrastructure, today the biobased and biodegradable plastics industry must face the challenge that composting as well as the use of compost as fertiliser is not permitted, even when the products comply with the strict criteria of the EN 13432 composting standard (http://esearch.cen.eu/esearch/Details.aspx?id=7543153). The policy mix in this area is complex and needs to be resolved otherwise the advantages of biodegradable plastics will be squandered. The alternative of anaerobic landfill disposal nullifies biodegradation in most cases, and does not address the landfill dilemma.

A central role for biobased plastics in the biorefineries of the future?

Many oil refineries that produce petrol and diesel operate on extremely low profit margins. Profit goals are met by integrating chemical and fuel production within a single operation. In petrochemical oil refineries, the 7–8% of crude oil dedicated to chemical production results in 25–35% of the annual profits [7]. Biorefineries are likely to be subject to the same market dynamics, especially as in most locations the production cost of biofuels is currently considerably higher than for petrol and diesel. With the plastics representing an intermediate production volume between high-volume fuels and low-volume chemicals, the biobased plastics may come to be central to the economics of the integrated biorefinery. Moreover, the highest production volume biobased chemicals could well be the ones used as monomers for the production of plastics.

The call for a policy level playing field

Policy support has been much greater for biofuels/bioenergy than for biobased plastics and chemicals. Bioenergy and biofuels not only receive high support in R&D, pilot and demonstration plants, but also receive strong ongoing support during commercial production (quotas, tax incentives, and green electricity regulations). This policy leads to a market distortion regarding feedstock availability and costs. If the energy market is more attractive because of related incentives and support, biorefinery development will be disproportionately focused on energy as the main output [8]. As indicated, this could severely affect the ability of an integrated biorefinery to operate profitably, and also the full positive climate change potential of biobased plastics would not be realised.

Setting some environmental targets, certification and labelling would simplify other policy areas

In the same manner that the US Renewable Fuels Standard (RFS2) has set GHG emissions savings targets along with volumetric mandates for biofuels [9], then environmental targets for bioplastics may be possible. This might have the effect of not only encouraging the development of the most effective bioplastics, but would also deter early investment in bioplastics with poorer environmental performance. It would also drive the need for LCA harmonisation. Narayan & Patel [10] have made an attempt to specify such targets. They have recommended that, relative to their conventional counterparts, biopolymers and natural fibre composites should:

- save at least 20 MJ (nonrenewable) energy per kg polymer;
- avoid at least 1 kg CO_2 per kg polymer and;
- reduce most other environmental impacts by at least 20%.

The purpose of certificates is to ensure that consumers are aware of the relevant properties of a material. Due to this important role, certificates are often accompanied by a label that may be placed on certified polymeric materials and relevant plastic items. However, certification and labelling are also ripe areas for policy harmonisation to offer both producers and the consumer clarity of information and choice.

Disclaimer statement

The opinions expressed and arguments employed herein are those of the author(s) and do not necessarily reflect the official views of the OECD or of the governments of its member countries.

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