Chapter 3

Trends in industry and products

This chapter examines recent trends in biofuels, bio-based chemicals and bioplastics. There is also some discussion of the future critical role of the integrated biorefinery. Biofuels have, unsurprisingly, dominated industrial biotechnology of late, and is reflected in recent country policies to promote biofuels production. The platform chemicals concept is explored and the platform chemicals that are likely to be important initially in the integrated biorefinery are identified. Bio-based chemicals also cover bulk, fine and specialty chemicals. Recent advances in biodegradable plastics and bio-based plastics have seen the market potential grow quickly as applications far beyond traditional packaging applications have started to emerge. In particular, the emergence of bio-based thermoplastics is set to affect the plastics world significantly, with very steep growth predicted over the next few years. Biofuels have enjoyed a wide range of supportive policy measures, but bio-based chemicals and bioplastics have not.

This chapter looks at recent developments in the liquid biofuels industry and some of the international policy issues involved. A significant development in 2010 was the US volume mandates which also specified the required reductions of greenhouse gas (GHG) emissions for the different categories of these fuels to 2022. In addition, bioplastics production has increased sufficiently to treat them separately from other bio-based chemicals. In future there may be a blurring of the boundaries between bio-based chemicals and biopolymers, as indicated by the production of bio-based ethylene to produce polyethylene.

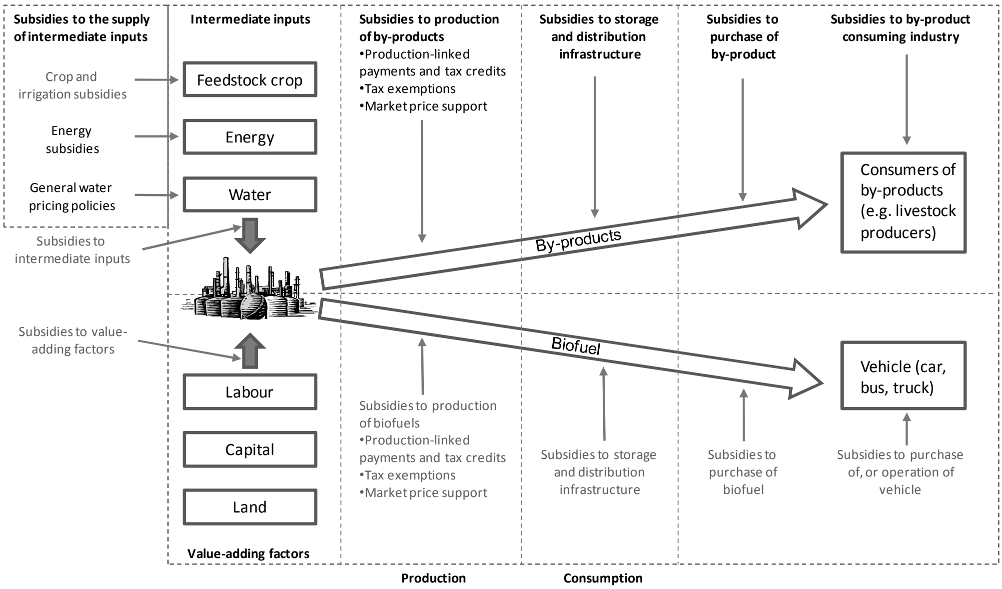
Biofuels

To some extent, biofuels have taken over the industrial biotechnology agenda in recent years. The year 2005 has been regarded as the tipping point for biofuels, when the demand created by drivers such as energy security put biofuels, and arguably industrial biotechnology more generally, high on the policy agenda. As noted by *Industrial Biotechnology – News* (2009), "Assuming an average biorefinery size of 40 million gallons per year, the USDA estimates that meeting the RFS2 advanced biofuels goals will mean the building of 527 biorefineries, at a cost of USD 168 billion". Between 2005 and 2008 the construction of corn ethanol plants in the United States exploded. One of the desired effects was a revitalisation of rural America; to some extent this seems to have happened (Wyse, 2008).

It was not long before controversies arose, such as the debates on sustainability (Goldemberg *et al.,* 2008) and food *vs.* fuel (Zhang *et al.,* 2010; Mueller *et al.,* 2011). Land use is an absolutely central issue in both of these debates (Heinen and Johnson, 2008). Policy and investment interest started to shift to biofuels other than corn-derived ethanol. Soaring oil prices help to maintain interest in biofuels at a high level, and indeed there is evidence that the food price spikes of 2007-08 had more to do with oil prices than with biofuels (Harvey and Pilgrim, 2011).

US policy measures, if successful, will drive the large-scale development of biofuels. In particular the Energy Independence and Security Act (EISA) (2007) and the Farm Bill (2008), which between them set volume mandates, created tax incentives, and provided funding for demonstration plants, will pave the way for very large investments in research and infrastructure and create further rural regeneration while working towards the aim of energy security. In fact, governments can and have intervened at many different points in the value chain for biofuels. Figure 3.1, for example, demonstrates the different points at which subsidies (direct and indirect) can be applied.

Figure 3.1. Different points in the biofuel supply chain to which subsidies can be applied



Source: Steenblik R (2007). Biofuels – at what cost? Government support for ethanol and biodiesel in selected OECD countries. The Global Subsidies Initiative (GSI) of the International Institute for Sustainable Development (IISD).

Biofuel categories

As noted, "biofuels policy" has gone well beyond corn-based ethanol and now applies to a broad range of biofuels. A useful categorisation of existing and future biofuels is as follows (US EPA, 2010):

- *Renewable fuel* refers to bioethanol and biobutanol derived from cornstarch (in terms of the volume mandate, the vast majority is bioethanol from cornstarch, more generally known as first-generation bioethanol).
- *Biomass-based diesel* refers to both biodiesel and renewable diesel from soy oil or waste oils, fats, and greases, as well as biodiesel and renewable diesel produced from algal oils.
- *Advanced biofuels* accommodates ethanol from sugarcane. It complies with the applicable 50% greenhouse gas (GHG) reduction threshold for advanced biofuels.

- *Cellulosic biofuels* refers to cellulosic ethanol and cellulosic diesel. For the EISA volume mandate, this effectively refers to cellulosic ethanol. It is also known as second-generation ethanol.

Potential disruptive technology on the horizon

Much of the effort on the supply side for biofuels currently focuses on overcoming remaining barriers, with "disruptive technologies" receiving much attention. In a study of disruptive technologies in transport fuels conducted by Accenture (Stark *et al*., 2009), "disruptive" was defined as:

- Scalable: potential impact of greater than 20% on hydrocarbon fuel demand by 2030.
- GHG: savings greater than 30% relative to the hydrocarbon it replaces.
- Cost: competitive at an oil price of USD 45 to USD 90 per barrel, at commercial date.
- Time to market: commercialisation in less than five years.

Production of algal biofuels in particular has the potential to be disruptive due to the potentially very high yields (Table 3.1).

Table 3.1. Yields of oil from various crops, compared with the potential of algae

Crop	Oil yield (gallons/acre)
Corn	18
Cotton	35
Soybean	48
Mustard seed	61
Sunflower	102
Rapeseed	127
Jatropha	202
Oil palm	635
Algae	10 000

Source: Pienkos PT (2009). Algal biofuels: ponds and promises. Presented at the 13th Annual Symposium on Industrial and Fermentation, 1 May 2009, NREL/PR-510-45822.

However, of all the technologies Accenture reviewed, algal technology was deemed the most difficult and the one that would take the longest to achieve commercial scale. Nonetheless, some companies claim that the first commercial plants will be available soon. Darzins (2008) indicated that, as of 2008, seven US government laboratories, 30 US universities, and around 60 biofuels companies were conducting research in this area. Intense efforts are also being made in other parts of the world, including Australia, Europe, the Middle East and New Zealand (Pienkos and Darzins, 2009).

Algae are attracting the attention of the oil majors. ExxonMobil has committed to invest USD 600 million in algae research in co-operation with Synthetic Genomics; Chevron has investment in Solazyme; Valero in Solix; Shell in Cellana (now wholly owned by HR BioPetroleum); and BP in Martek. This would indicate that the major oil companies are in algae for the long term.

Joule Unlimited Inc. of the United States is working on a direct algal process that combines an engineered cyanobacterial organism supplemented with a product pathway and secretion system to produce and secrete continuously an alkane diesel product. The process is closed and uses industrial waste CO_2 at concentrations 50-100 times higher than atmospheric (Robertson *et al.*, 2011). If successful this technology has the potential to change the dynamics of biofuel production as it does not require the extraction of fuels from large amounts of biomass.

Outlook for biofuels

The outlook is encouraging. It is being driven mainly by regulatory support (Denis and Oberman, 2010). The global market will likely grow from 25 billion gallons of biofuels a year in 2010, to 65 billion by 2020. Of the anticipated 65 billion gallons, 10-15 billion are expected to be second-generation biofuels.

According to Denis and Oberman, regulation is crucial for ensuring this growth, with 31% of survey respondents naming government mandates as the major driver. Improved energy security was identified as a key driver by 20%, development of affordable fuels by 19%, the need for sustainable fuels by 19% and other drivers by 11%.

However, the biofuels industry faces several major challenges:

- Availability of broader biomass feedstocks at affordable prices: in 2008, the cost of feedstock was quoted as the most significant impediment to the growth of industrial biotechnology (USITC, 2008).

- Next-generation biofuels (lignocellulosic ethanol, biodiesel, bio-butanol) must quickly reach steady-state economics, which requires the industry to think of the whole value chain. The United States has incentives at many points in the chain.
- There must be agreement on a blend wall solution (Carey, 2008), for example, by increasing the ethanol-in-gasoline blend beyond 10%.
- Robust yet practical sustainability standards must be established. In this regard, the industry faces either too few regulations or too many. For an overview on progress to date, O'Connell *et al.* (2009) make specific statements about relevance of biofuel standards to biomaterials.
- Investor confidence must be restored. Lack of capital ranks as the second largest impediment to commercialisation of liquid biofuels or bio-based chemicals.

The importance of government mandates

The US Renewable Fuels Standard (RFS2) (Federal Register, 2010) lays out the strategy and targets for the United States to 2022. It therefore covers current and near-term biofuels development, but also has a provision for the inclusion of new technologies.

The mandated RFS2 goal is to use at least 36 billion gallons of bio-based transport fuels by 2022 (USDA, 2010), of which 15 billion gallons can come from conventional biofuel sources such as corn ethanol, *i.e.* the renewable fuel category. Of the remaining 21 billion gallons of advanced biofuels needed to achieve the total 36 billion gallon goal, 16 billion gallons must come from advanced cellulosic biofuels (fuels made from cellulosic feedstocks that reduce greenhouse gas emissions by at least 60% relative to gasoline), and biomass-based diesel must contribute no less than 1 billion gallons. An additional 4 billion gallons are to come from advanced biofuels. In all, the mandate will displace about 14% of the motor gasoline demand in 2022.

The US EPA projects that by 2022 15 billion gallons of conventional biofuels could come from the current or planned production capacity of cornstarch ethanol. The US biofuels industry is on track to produce 1 billion gallons of biodiesel by 2022. The greatest challenge is to meet the volume mandate for cellulosic fuels. The intention is to develop strategic partner-ships with the private sector to expedite the development and deployment of research, development and demonstration projects, facilitate the siting of biorefineries, and identify potential barriers to meeting transport and distribution needs for an advanced biofuels industry. Without doubt, this is the most difficult volume mandate to meet by 2022.

Assuming an average biorefinery size of 40 million gallons a year, the USDA estimates that meeting the RFS2 advanced biofuels goals will mean building 527 biorefineries, at a cost of USD 168 billion. The infrastructural implications seem daunting, but the USDA expects the market to react to this need (USDA, 2010).

An interesting policy aspect of EISA 2007 and the volume mandates is the inclusion of targets on the lifecycle analysis (LCA) of these different types of biofuels. Standardisation and LCA are policy areas that are ripe for more detailed study. For each renewable fuel pathway, GHG emissions were evaluated over the full lifecycle, including production and transport of the feedstock; land use change; production, distribution and blending of the renewable fuel; and end use of the renewable fuel. The GHG emissions were then compared to the lifecycle emissions of 2005 petroleum baseline fuels (base year established as 2005 by EISA) displaced by the renewable fuel, such as gasoline or diesel. The thresholds are specified in Table 3.2. This is significant because it is the first time that lifecycle emissions reduction has become a legal requirement.

Table 3.2. Greenhouse gas thresholds as specified in EISA

Percentage of reduction from 2005 baseline

Fuel	GHG threshold as specified in EISA
Renewable fuel	20%
Advanced biofuel	50%
Biomass-based diesel	50%
Cellulosic biofuel	60%

Source: US EPA (2009). EPA proposes new regulations for the national renewable fuel standard program for 2010 and beyond. EPA-420-F-09-023, May.

To achieve the 36 billion gallons of renewable biofuels by 2022, the USDA concluded that:

- A rapid build-up in production capabilities is needed to meet the targets for cellulosic biofuels.
- The monetary investment for biorefineries is substantial. Second-generation biofuels may imply a very high capital cost, perhaps over five times that of similar capacity starch ethanol plants (Wright and Brown, 2007).

- It is important to consider both sides of the market – the production/supply side and demand/consumption side – and how they respond to the RFS2 mandate.
- Current infrastructure needs, in the form of blender pumps and rail and trucking infrastructure, even the construction of dedicated pipelines, are in varying stages of being addressed by the market.
- The US farm sector is capable of producing a diverse complement of feedstocks to make the biofuels industry a truly national effort.
- A process for identifying bottlenecks and barriers related to locating biorefineries, involving the federal government, Congress, states, the industry and interested stakeholders, can help facilitate a biorefinery system that is national in scope.

Table 3.3 shows the support given to the construction of major biofuels facilities by the US Department of Energy (DoE), as published at the end of 2009. The USDA has also been instrumental in funding many necessary aspects of biofuels and other bio-based materials development in the United States *e.g.* basic and applied research, incentives to promote the production of biomass, loan guarantees and grants to support development of processing facilities for bioproducts, importantly including biofuels.

Table 3.3. US Department of Energy grants for biorefineries announced at end of 2009

Grantee	DoE grant (USD millions)	Non-federal (USD millions)	Location (state)	Description
Pilot scale				
Algenol Biofuels	25	33.915	TX	Ethanol from CO_2 and seawater, 100 000 gallons fuel-grade ethanol per year.
American Process	17.944	10.148	MI	890 000 gallons ethanol and 690 000 gallons potassium acetate per year.
Amrys Biotechnologies	25	10.489	CA	Diesel substitute from sorghum fermentation, co-products lubricants, polymers and other petrochem substitutes.
Archer Daniel Midland	24.834	10.946	IL	Acid treatment of biomass to make liquid fuels. Will also make ethyl acrylate.
Clearfuels Tech	23	13.433	CO	Diesel and jet fuel from woody biomass.
Elevance Renewable Sciences	2.5	0.625	IA	Preliminary engineering design for a future facility producing jet fuel, renewable diesel and high value chemicals

Grantee	DoE grant (USD millions)	Non-federal (USD millions)	Location (state)	Description
Gas Technology Institute	2.5	0.625	Il	Preliminary engineering design for green gasoline and diesel from woody biomass, agricultural residues and algae.
Haldor Topsoe	25	9.701	Il	Convert wood to green gasoline through gasification, 21 tons feedstock per day.
ICM	25	6.268	MO	Modify ethanol plant to produce cellulosic ethanol from switchgrass and sorghum.
Logos Technologies	20.445	5.113	CA	Convert switchgrass and woody biomass to ethanol by biochemical process.
Renewable Energy Institute	19.980	5.116	OH	Green diesel from agricultural and forest residues, 25 tons of feedstock per day.
Solazyme	21.765	3.857	PA	Validate economics of commercial-scale production of advanced biofuels, algal oil that can be converted to oil-based fuels.
UOP LLC	25	6.685	HI	Green gasoline, diesel, jet fuel from agricultural residue, woody biomass, algae.
ZeaChem	25	48.4	OR	Hybrid poplar trees for fuel-grade ethanol.
Demonstration scale				
BioEnergy International LLC	50	89.589	LA	Succinic acid from sorghum.
Enerkem Corp	50	90.470	MS	Woody biomass and municipal solid waste (MSW) biomass for ethanol and green chemicals
INES New Planet Energy LLC	50	50	FL	Ethanol and electricity from wood and vegetable residues, 8 million gallons ethanol and 2 megawatts electricity per year.
Sapphire Energy	50	85.064	NM	Algae in ponds to convert to green fuels.
Increased funding to existing biorefinery projects				
Bluefire LLC	81.134	223.227	MS	Ethanol from woody biomass, mill residues and sorted MSW.

Source: Adapted from Industrial Biotechnology (2009). December 2009, 5(4): 193-205, *http://dx.doi.org/10.1089/ind.2009.5.193*

Tariffs and other trade barriers

Most countries producing ethanol apply a most-favoured nation (MFN) tariff that adds at least 25%, or USD 0.13 per litre, to the cost of imported ethanol. Some tariffs, such as the EU's for denatured alcohol, can add 50% to the import cost. Mandating increasing levels of biofuels in national transport fuel mixes, while maintaining such barriers to cheaper imports, may inhibit the growth and development of developing countries, many of which have a comparative advantage in production of biofuels compared with most OECD members (Steenblik, 2007).

Subsidies

Although subsidies are generally thought of as cash payments to a particular company or an individual, this simple definition misses many of the other means that governments use to assist the biofuels industry (Doornbosch and Steenblik, 2007). A wide range of policies, including special reductions, privileged tax advantages and relatively low insurance requirements are used to provide benefits to specific groups (OECD, 2007).

The Global Subsidies Initiative has developed a framework to examine support levels at different points in the supply chain for biofuels, from the production of feedstocks to final consumers. At the beginning of the supply chain are subsidies to intermediate inputs. In several countries, the largest of these are subsidies to producers of feedstock crops used to make biofuels. Further down the chain are subsidies directly linked to output; these include the protection from foreign competition provided by import tariffs on ethanol and biodiesel; exemptions from fuel excise taxes; and grants or tax credits based on the volume produced, sold or blended. For a more comprehensive discussion of the wide range of subsidy-based policy instruments, see Doornbosch and Steenblik (2007).

National bio-energy policies and activities

In addition to the US policies that have led to the rapid and marked expansion of the biofuels industry in that country, many others have biofuel policies in place or in formulation. REN21, the Renewable Energy Policy Network for the 21st Century, reported that 73 countries (many of them developing countries) had bioenergy targets as of early 2009 (REN21, 2009). Some of the following draws heavily on a recent paper on the subject (Wonglimpiyarat, 2010).

Australia

As Australia eyes a USD 25 billion trade deficit in petroleum products by 2015, the federal government is providing AUD 20 million from the Australian Centre for Renewable Energy (ACRE) to establish an Australian Biofuels Research Institute. This builds on other support for alternative fuels including the AUD 15 million Second Generation Biofuels Research and Development Program (GEN2) through ACRE. These programmes are part of the government's AUD 5 billion Clean Energy Initiative which supports the development of clean energy and energy efficiency technologies. The government has also provided AUD 11 million for the development of biomass conversion capabilities in five facilities, as part of the National Collaborative Research Infrastructure Strategy.

Brazil

In the 1970s oil shock, the Brazilian government introduced fuel ethanol to reduce oil consumption. In 1975 it launched the national alcohol programme PróÁlcool. Soaring oil prices put Brazil at the forefront of the biofuel movement. Brazil subsidised biofuel during market development until economies of scale allowed fair competition with oil products. Fuel ethanol production was 22.5 million kl (kilolitres) in 2007. By 2004, ethanol in Brazil had become economically competitive with gasoline based on international prices for oil (equivalent to USD 40 per barrel) (Goldemberg, 2008). At these costs, the production of ethanol from sugarcane is much cheaper that from crops such as corn, wheat and sugar beet. The Brazilian federal policy on biodiesel is aimed at alleviating rural poverty (stimulating rural activities to increase employment in rural areas). It is an interesting historical note that energy security was the main driver at the time of the launch of the PróÁlcool programme. At the time climate change had only just started to emerge as a global concern. However, GHG emissions savings has become an additional driver for bioethanol production in Brazil.

Canada

Like the United States, Canada has introduced mandates and subsidy programmes in support of infrastructure for biofuel facilities and ethanol and biodiesel production (*e.g.* the ecoAgriculture Biofuels Capital Initiative and the ecoENERGY for Biofuels programme). Canada has set a national mandate of 5% of renewables, and Ottawa has pledged financial support of CAD 100 million in its Climate Change Plan.

China

As an agricultural country with a population of 1.3 billion, China cannot sacrifice food security for energy. Government policy supports food self-sufficiency for the sake of national security. The Chinese government has therefore clamped down on the use of corn and other edible grains to produce biofuel. However, biofuel production is seen as an essential and strategic component of a secure economy and diversified energy policy. China cultivates jatropha for biodiesel production of 1.76 billion gallons a year and has encouraged the production of biofuel, such as ethanol and methane, from renewable resources in order to reduce dependence on imported oil. In 2005, the National Key R&D Programme included development of cellulosic ethanol and has now set a target of 15% of biofuel in total transport fuels by 2020.

China is establishing industrial parks for chemical R&D. Tianjin Economic-Technological Development Area (TEDA), one of three national demonstration eco-industrial parks (EIPs), has created a complex network based on industrial symbiosis. One of its four pillar industries is biotechnology and pharmaceuticals (Shi *et al*., 2010). High-technology projects for liquid biofuels and bio-based products are funded by the National High-Technology R&D programme. Feedstock prices are regulated, reportedly held below international levels, and sometimes frozen. Support for biofuels includes tax benefits, preferential loans, and assistance for demo-scale plants from non-food feedstocks. Support for bio-based chemicals includes various incentives for profitable and efficient producers, and preferential tax treatment for selected firms in emerging biochemical industries.

China leads efforts to re-commercialise the acetone, butanol, ethanol (ABE) fermentation process for the production of bio-butanol. Over USD 200 million has recently been invested in China to install annual capacity of 0.21 million tonnes of solvent with plans to expand to 1 million tonnes. Six major plants produce about 30 000 tonnes of butanol a year from cornstarch (Green, 2011).

European Union

Europe has many political, environmental and scientific initiatives that involve industrial biotechnology, but they are somewhat uncoordinated. In January 2007, an energy and climate change package proposed to cut greenhouse gas emissions by at least 20% by 2020 (largely through energy measures).

In the early years of EU bioenergy policy, biofuels were supported mainly through Directive 2003/30 (Official Journal of the European Union, 2003). The main objective was to trigger domestic production and consumption in member countries through fiscal stimulus and incentives (Ninni, 2010).

A major EU landmark was the publication of the Renewable Energy Directive (Official Journal of the European Union, 2009), which established a common framework for the promotion of energy from renewable sources. It set mandatory national targets for the overall share of energy from renewable sources in gross final consumption of energy and for the share of energy from renewable sources in transport. It also established sustainability criteria for biofuels and bioliquids. In light of recent research on the risks of biofuels, the European Commission proposed to favour the use of biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material over the use of first-generation biofuels (Bringezu *et al.*, 2009).

Germany

In 2004 the German government made available a biofuel tax exemption in a bid to reduce CO_2 emissions. It also introduced subsidy programmes which have helped the German biodiesel industry to become a world force. Germany has been the world leader in biodiesel production and use, with about two-fifths of global production and almost half of global consumption in 2006 (Bringezu *et al.*, 2009). Biodiesel production capacity in 2007 was 5 million tons. Biodiesel has helped Germany make the transition to the next generation of biofuels; the government aimed to meet the EU's target for biofuel use of 5.75% in 2010.

India

India stands sixth in the world in energy demand and accounts for 3.5% of the world's commercial energy consumption. The transport sector mainly relies on diesel. India has turned to bio-based energy to reduce dependence on imported oils. It has about two-thirds of the world's jatropha plantations and thus leads the way in planting and cultivating jatropha on industrial scale for biodiesel production (600 million gallons a year). It aims to replace 20% of India's diesel consumption with biodiesel by blending petro-diesel with a planned 13 million metric tons of jatropha-based biodiesel by 2013.

Japan

Japan is the world's third-largest oil consumer after the United States and China. Following the oil crises of the 1970s, the Japanese government embarked on national projects to develop alternative energy resources and raise the productivity of bioethanol production. Currently, the government allows oil companies to blend about 3% of ethanol into gasoline. In future, oil companies plan to introduce ethyl tertiary butyl ether (ETBE) mixed gasoline to meet potential demand of approximate 1.8 million kl per year. Japan planned to replace about 500 000 kl (3.14 million barrels) per year of transport fuels with bioethanol by 2010.

Japan is engaged in a mixture of public and private investment and development projects in other countries. In order to help reduce GHG emissions Japan will provide technical assistance to Southeast Asia, in particular to Thailand and Vietnam. Several Japanese trading companies have started to invest in Malaysia and Indonesia to produce biodiesel from palm oil and bioethanol from sugar cane and jatropha. Some Japanese trading companies have shown interest in Brazilian ethanol investments (USDA Foreign Agricultural Service, 2009).

Malaysia

Energy security and rural and economic development drove Malaysian R&D on biodiesel derived from palm oil as early as 1982. It is the world's second largest producer of palm oil. The federal government's National Biofuel Policy was launched in 2005 with a strong focus on biodiesel. The policy aims to reduce the country's fuel import bill, to promote the demand for palm oil, the primary commodity for biofuel production, and to shore up the price of palm oil, especially during periods of low export demand. In Southeast Asia, Malaysia dominates the biodiesel market in terms of production capacity. It planned to mandate the use of biodiesel blend (2% blend) in fossil fuel used for transport in 2008 but postponed biodiesel mandates owing to poor economic conditions.

Thailand

Thailand typifies the developing world's dilemma of sustaining growth while being highly dependent on imports of crude oil (which currently account for more than 10% of GDP) (Siriwardhana *et al.*, 2009). The Thai government has supported power generation using all types of renewable fuel. The development of biodiesel for use in the transport sector is one of the top priorities of the current National Energy Policy and Strategy's efforts to strengthen energy self-reliance. The country plans to have ethanol contribute 10% and biodiesel up to 3% of total fuel consumption in the transport sector by 2011. A study by Silalertruksa and Gheewala (2010) concluded that to enhance the long-term security of feedstock supply for sustainable bioethanol production in Thailand, policy makers should urgently promote increasing use of sugarcane juice, improved yields of existing feedstocks and production of bioethanol from agricultural residues.

Thailand is also encouraging the use of natural gas, ethanol-blended gasoline and biodiesel for industrial use. It has successfully encouraged the use of 10–20% ethanol blends through adoption of fiscal incentives. The Thai government has introduced E10 and E20 gasohol and subsidised the gasohol price with tax exemption from oil-related taxes.

An added dimension of the globalisation of biofuels is the growing need for internationally recognised standards. A tripartite task force involving Brazil, the European Union and the United States has begun working on establishing an internationally compatible standard for ethanol, in the interest of encouraging international trade (Tripartite Task Force Brazil, European Union and United States of America, 2007). In a White Paper published at the end of 2007, the committee outlined areas in which the fuel standards of the three regions could find common ground. These include the water content of ethanol, pH levels of the ethanol to be traded, and levels of phosphorus and other non-alcohol materials. The committee found that the only substantial difference among the standards was the EU water content requirement. Although the difference may seem small, the EU requirement means that US and Brazilian exporters that wish to send ethanol to Europe must add an additional step to ensure that the fuel they produce meets European standards. This incurs extra time and production costs and hinders the growth of international markets.

Research and development in biofuels

Like industrial biotechnology more generally, R&D and innovation are centrally important to the competitiveness and productivity of biofuels companies. In the United States, probably the most visible area of biofuels research is the development and adoption of cellulosic ethanol, a shift from the use of food crops to non-food crops as feedstock. A number of significant pilot and demonstration plants producing cellulosic ethanol have started operation.

R&D can have very large impacts on the industry. For example, Petrobras of Brazil and Novozymes have entered into an agreement to develop a production process for biofuel from sugarcane bagasse, a fibrous material remaining after sugar cane extraction (*Industrial Biotechnology*, 2010a). The agreement covers the development of enzymes and processes to produce lignocellulosic ethanol by an enzyme process. Bagasse-to-ethanol technology has the potential to increase Brazil's ethanol production by up to 40% without increasing crop areas. This will allow regional cellulosic ethanol production, getting around the problem of long-distance ethanol transport.

US R&D activities were robust in 2008, but the 2008 USITC survey identified major impediments (Table 3.4). Significantly, over one-quarter of respondents reported that these were severe enough to dissuade them from pursuing any industrial biotechnology R&D activity.

Table 3.4. Impediments to R&D in industrial biotechnology

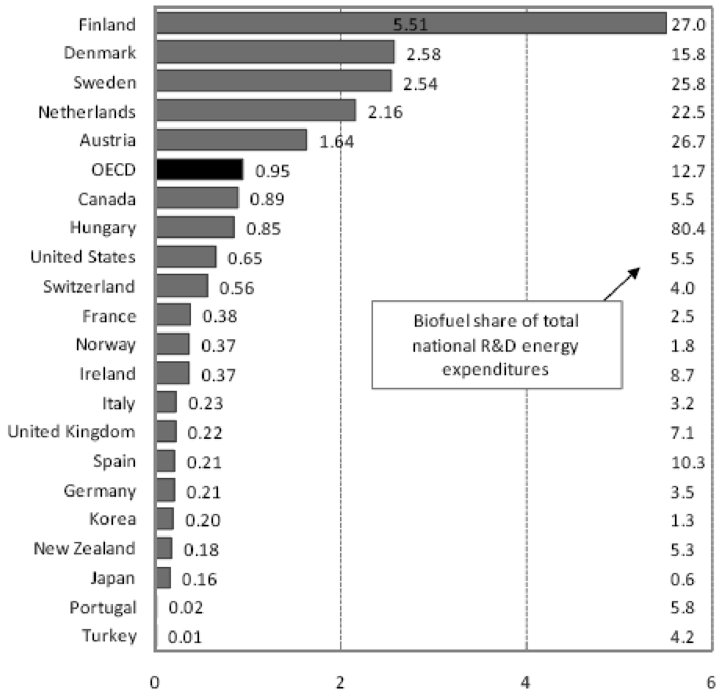
Impediment	Percent responding very significant
Lack of capital (debt or equity)	54
US regulatory requirements	30
Limits of available technology	30
Inability to qualify for federal grants	26
Inability to qualify for state grants	25
Lack of human resources	24
Poor public perception of bio-products	22
Inability to establish alliances	15
Patent barriers	10
Access to university technology	9

Source: Adapted from USITC (2008). Industrial biotechnology: development and adoption by the US chemical and biofuels industries. Investigation no. 332-481. USITC Publication 4020, July.

Far and away the most important impediment to industrial biotechnology R&D is perceived to be finance-related, in terms of lack of capital and of ability to qualify for grants. Given the top-down approach adopted by the United States, it is very likely that the situation is the same in most other parts of the world. For biofuels specifically, and industrial biotechnology more generally, funding of R&D is a global issue.

Although the United States dwarfs other nations in terms of the actual amounts spent on biofuel R&D, it is interesting to note that several Nordic countries rank highest for per capita government spending on such R&D (Figure 3.2); Finland leads the way, followed by Denmark and Sweden. In Finland and Sweden, the forest sector is relatively large and plays a vital role in both the traditional economy and their growing bio-economies.

Figure 3.2. Per capita government budgets for biofuel R&D, 2007



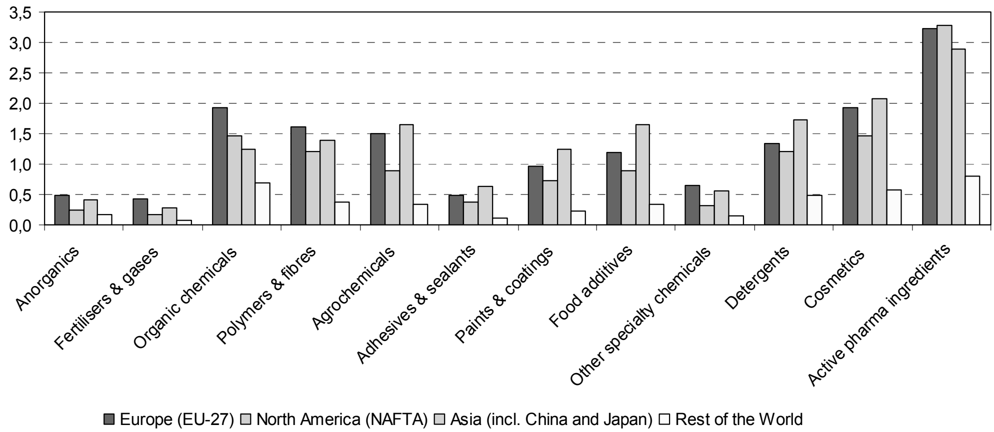
Note: Energy allocation data for Austria, France, Finland and the Netherlands are for 2006.

Source: OECD, based on data from the International Energy Agency, Energy Technology database R&D edition; and OECD, MSTI 2008/1 data for national populations in 2006 (latest available year for all countries), April 2009.

Bio-based chemicals

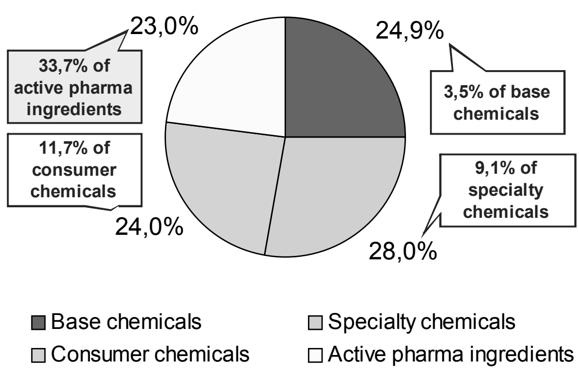
The list of chemicals that could potentially be produced via a bio-route is far too large to be defined at this early stage in the development of the bio-based economy. It is more relevant to look at sales volumes and the types of bio-based chemicals by sub-segments of the chemical industry. Global sales of products made by biotechnology processes in 2007 totalled approximately EUR 48 billion (Figure 3.3) or 3.5% of total chemical sales (excluding pharmaceutical products but including active pharmaceutical ingredients) (Festel, 2010). This approximately concurs with the data of NationMaster (Winters, 2010), which showed that less than 4% of US chemical sales are bio-based. The amount is predicted to increase to EUR 135 billion by 2012 (OECD, 2009). The breakdown by segment is given in Figure 3.4.

Figure 3.3. Biotechnology sales per sub-segment, 2007



Source: Discussion paper, OECD workshop on outlook on industrial biotechnology, Session II on industry structure and business models for industrial biotechnology, January 2010.

Figure 3.4. Bio-based chemical sales by segment, 2012



Source: Discussion paper, OECD workshop on outlook on industrial biotechnology, Session II on industry structure and business models for industrial biotechnology, January 2010.

By 2017, biotechnology sales are projected to have reached EUR 340 billion, with polymers and fibres replacing cosmetics to become the second largest sub-segment in sales behind active pharmaceutical ingredients (Festel, 2010).

Platform chemicals and integrated biorefineries

A platform chemical, as the name implies, is one which is produced in large volumes and is used to produce other chemicals through conversion technologies. It makes sense to identify the platform chemicals that form the basis of large-scale production for at least three reasons:

- Large-scale production will make it possible to create economies of scale. This will improve the competitiveness of biological as compared to petrochemical production.
- For the integrated biorefinery model to work, platform chemicals need to be identified so that the necessary production technology can be built at the refinery site.
- It is likely that production of bio-based chemicals will be driven by biofuel production, as in the case of the oil refinery, as this model offers much higher returns on investment.

Various attempts have been made to define the list of platform chemicals that will be required in the early integrated biorefineries. For example, Werpy and Petersen (2004) made a list for the US DoE of 15 target molecules that could be produced from carbohydrate raw materials. Table 3.5 gives a convenient categorisation of the core chemical products of lignocellulosic biorefineries according to their route of production.

Table 3.5. Platform chemicals that are potential targets for lignocellulosic biorefineries

Class	Chemicals	Production route
Lower alcohols	Methanol, ethanol, 1-butanol, isobutanol	Fermentation or biomass-derived syn gas
Diols	1,2-ethane diol, 1,2-propane diol, 1,3-propane diol	Fermentation or chemo-catalytically
Polyols	Sorbitol, xylitol	Hydrogenation of cellulose and hemicelluloses, respectively
Dicarboxylic acids	Acetic, lactic, succinic, 3-hydroxypropanoic	Fermentation

Source: Adapted from Sheldon RA (2011). Utilisation of biomass for sustainable fuels and chemicals: Molecules, methods and metrics. *Catalysis Today*.

Succinic acid is a very good example for the platform chemical concept. Succinic acid is considered to be an important platform chemical which can be used directly or as an intermediate in the manufacture of paints, plastics, food additives, and other industrial and consumer products (Bechthold *et al*., 2008). It is mainly produced by a chemical process from *n*-butane/butadiene via maleic anhydride, utilising the C4-fraction of naphtha in quantities of about 15 000 tonnes per year. However, fermentation-derived succinate has the potential to supply over 270 000 tonnes of industrial products annually (Zeikus *et al*., 1999). What is more, while ethanol fermentation produces CO_2, succinate fermentation consumes it. This makes bio-succinate production a very green technology.

The divide between commodity chemical and platform chemical is often blurred. For example, bioethanol and other lower alcohols are commodity chemicals for a variety of uses. However, they can also be used as precursors for the production of olefins, thereby creating a direct link to petrochemical refineries. Sheldon also argues that future biorefineries might realistically produce acrylic and methacrylic acids and caprolactam.

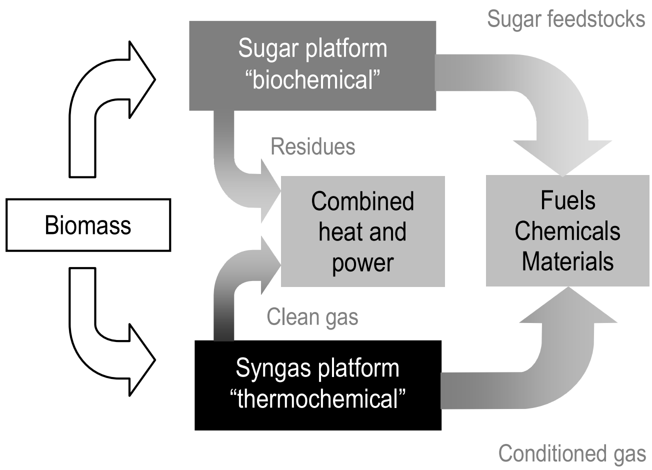
One class of chemicals missing from this list is the aromatics. The primary biological source would be the aromatic amino acids, derived from the protein fraction of biomass or produced by fermentation. These could also be a source of some aromatics such as styrene. Alternatively, butadiene produced from bioethanol could be converted to aromatics by known technologies.

Two very large production commodity platforms not included are bio-based ethylene and propylene, discussed below in terms of their roles in the production of polyethylene and polypropylene. Bio-based ethylene and propylene differ from the platform chemicals in Table 3.5 in that the biological component is bioethanol, from which ethylene (Morschbacker, 2009) and propylene (Sakaki *et al*., 2009) are derived chemically. If such bio-based ethylene and propylene achieve large production status, bioethanol would be the ultimate biological platform chemical. Petrochemically derived ethylene is already the largest production organic chemical globally (Chemical and Engineering News, 2006).

Integrated biorefineries

Integrated biorefineries (Figure 3.5) have to be able to convert efficiently and simultaneously a broad range of industrial biomass feedstocks into affordable biofuels, energy and a wide range of biochemicals and biomaterials. These goals are met by integrating chemical and fuel production within a single operation (Bozell, 2008). In such an operation, high-value products become an economic driver that provides higher margins to support low-value fuel, leading to a profitable biorefinery operation that also has an energy impact. This is how petrochemical oil refineries are operated: the 7% to 8% of crude oil dedicated to chemical production results in 25% to 35% of the annual profits of integrated petrochemical refineries.

Figure 3.5. An integrated biorefinery concept



Source: www.nrel.gov/biomass/biorefinery.html.

Table 3.6. Biomass sources and primary products in selected second-generation biorefineries in Europe

Location	Country	Biomass	Primary products
Karlsruhe	Germany	Straw	Synthesis gas
Freiberg	Germany	Dry wood, straw	Synthesis gas
Schwedt	Germany	Dry wood, straw	Synthesis gas
Südlohn-Oeding	Germany	Waste edible fats	Biodiesel
Embden	Germany	Waste edible fats	Biodiesel
Kleisthöhe	Germany	Waste edible fats, rapeseed oil	Biodiesel
Güssing	Austria	Wood chips	Producer gas, energy
Lappeenranta	Finland	Bakery, sweet factory waste	Bioethanol
Närpiö	Finland	Potato flake factory sidestream	Bioethanol
Harmina	Finland	Bakery waste	Bioethanol
Pitea	Sweden	Black liquor	DME
Värnamo	Sweden	Wood chips, straw pellets	H_2-rich gas
Schaffhausen	Switzerland	Grass	Gas, technical fibres
Utzenaich	Austria	Grass silage	Gas, technical fibres, proteins

Source: Adapted from Lyko H, Deerberg G and Weidner E (2009). "Coupled production in biorefineries – Combined use of biomass as a source of energy, fuels and materials". *Journal of Biotechnology* 142, 78-86.

However, if integrated biorefineries are to utilise a range of feedstocks efficiently (Table 3.6), this will require significant technology development and financial risk. The construction of biorefinery pilot and demonstration plants is not only costly, it also requires bringing together market actors along new and highly complex value chains. These include the diverse suppliers of biomass raw materials (*e.g.* farmers, forest owners, wood and paper producers, biological waste suppliers, producers of macro- and micro-algae), the industrial plants that convert the raw materials and the industries that provide them with the necessary technologies, and the various end users of intermediate or final products. Another key issue will be the sustainability and security of feedstock supplies.

Countries such as the United States, Brazil, China and others are increasing investments into research, technology development and innovation, and supporting large-scale demonstrators. Europe is behind other world players in this area and concerted action is needed for Europe to reach its 2020 targets. The US DoE is co-financing the commercial demonstration of an integrated bio-refinery system for the production of liquid transport biofuels, bio-based chemicals, substitutes for petroleum-based feedstocks and products, and biomass-based heat/power generation (European Commission, 2011).

Bulk chemicals

The selected bio-based products in Table 3.7 may be good candidates for gaining large market shares of bulk chemicals as their future production costs are expected to be comparatively low, whereas the current production capacity of petrochemical equivalents is high (Dornburg *et al.*, 2008; Hermann and Patel, 2007).

Table 3.7. Selected bio-based chemicals and petrochemical counterparts

Bio-based chemical	Reference petrochemical
Ethyl lactate	Ethyl acetate
Ethylene	Ethylene
Succinic acid	Maleic anhydride
Adipic acid	Adipic acid
Acetic acid	Acetic acid
n-Butanol	*n*-Butanol

Source: Dornburg V, Hermann BG and Patel MK (2008). Scenario projections for future market potentials of bio-based bulk chemicals. *Environmental Science and Technology* 42, 2261-2267.

Medium to high volumes of acetic and adipic acids, ethylene and *n*-butanol are produced from fossil resources, but only low volumes of ethyl lactate and succinic acids. Ethyl lactate is a solvent that could replace ethyl acetate on a large scale, and succinic acid could be used in the production of 1,4-butanediol, polyesters and tetrahydrofuran.

The extent to which these substitutions will occur in future depends on a variety of factors, but the crucial factors are petrochemical feedstock prices and fermentable sugar prices. Both are difficult to predict. Dornburg *et al.* (2008) concluded that to achieve high market potential for bio-based chemicals in Europe technology developments in industrial biotechnology must proceed, biofeedstock prices have to be lower than current sugar prices, and fossil fuel prices must increase. Dornburg *et al.* used a number of scenarios to illustrate their thinking. In the scenario in which all assumptions favour the market potential of bio-based chemicals, the price of fossil fuels is assumed to be USD 83 per barrel from 2020 onwards, an amount already exceeded several times by 2011. They also concluded that in terms of energy use, GHG emissions and land use for feedstock availability, lingo-cellulosics were to be recommended as the basis for producing bulk bio-based chemicals from fermentable sugar.

Fine or specialty chemicals

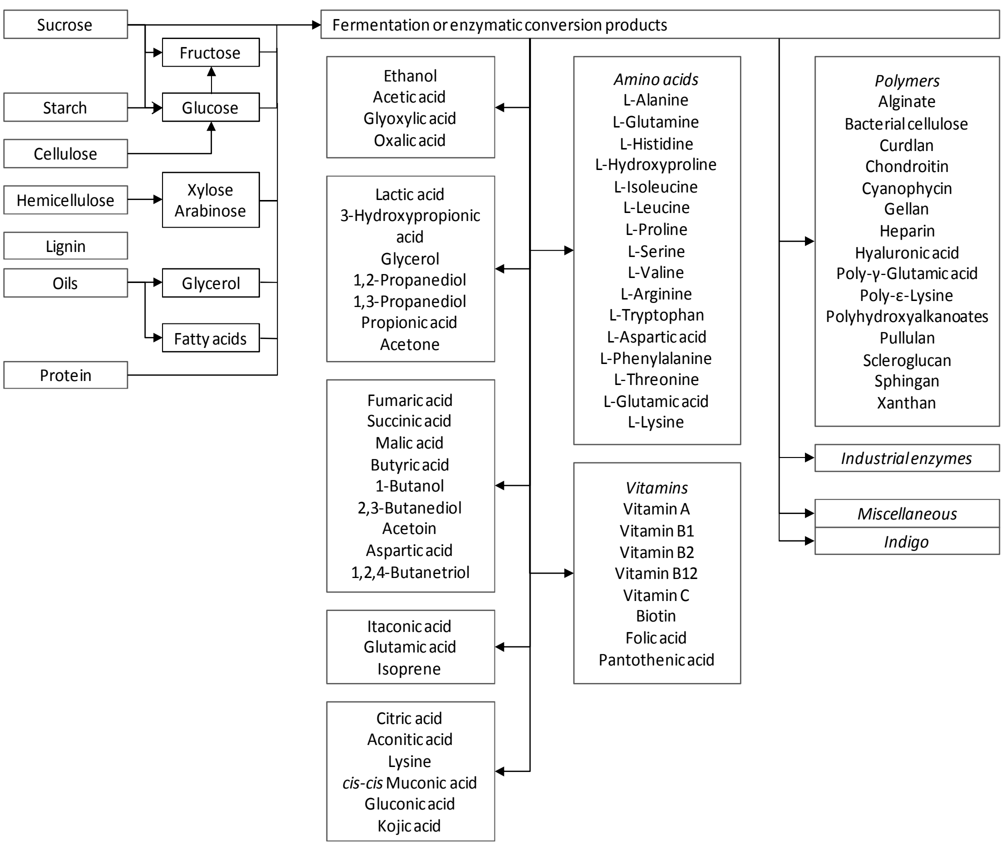
The difference between fine and speciality chemicals has always been hard to define. Here they are treated together. Pollak (2007) defined fine chemicals as “complex, single, pure chemical substances [...] produced in limited quantities (<1 000 metric tons per year) in multi-purpose plants by multistep batch chemical or biotech processes. They are sold for more than USD 10 per kilogram, based on exacting specifications, for further processing within the chemical industry.”

Apart from its production volume, riboflavin (vitamin B2) fits the category of fine chemical. Several thousand tons are produced yearly and are consumed mainly as food and feed additives (Hümbelin *et al.*, 1999). In recent years a number of producers have developed biotechnological processes to replace the more costly chemical synthesis of the compound. Besides the economic advantage, there are eco-efficiency benefits: the bio-technological process uses renewable sources, is more environmentally friendly and yields a product of equal or superior quality (van Loon *et al.*, 1996). Some of these advantages (OECD, 2001; EuropaBio, 2008) have been quantified:

- 40% cost reduction.
- 80% reduction in the use of non-renewable resources.
- 50% reduction of volatile organic compounds.
- 66% reduction in emissions to water.

Figure 3.6 summarises the relationship between the production of platform, bulk and fine chemicals via bio-based routes. It gives an indication of the breadth of the bio-based chemicals market. The potential for bio-based fine and specialty chemicals is substantial if the technology and economics of integrated biorefineries can be perfected.

Figure 3.6. Chemicals obtainable from major biomass constituents by established or potential biotechnological processes



Source: EuropaBio (2009). SME Platform. Access to finance: a call for action. 27 May.

Bio-based chemicals: The policy gap

Biofuels have gained a number of incentives that range from production incentives (such as per gallon tax incentives for the production of biofuels) to loan guarantees and grants for the construction of biofuel biorefineries. However, there is very little in the way of similar incentives for renewable chemicals and bio-based products (Carr *et al*., 2010). Efforts to try to redress the balance have begun. For example, the US trade organisation BIO has been working on a proposal for a production tax incentive for renewable chemicals and bio-based products. According to BIO, existing programmes, such as loan guarantee and grant programmes, should also be open to facilities producing non-fuel bio-based products.

The situation in Europe is similar, in that, in contrast to bioenergy and biofuels, there is currently no equivalent European policy framework to support bio-based materials (Carus *et al*., 2011). Bioenergy and biofuels receive strong support not only for R&D, pilot and demonstration plants, but also during commercial production (quotas, tax incentives, green electricity regulations and more). Without comparable support, there may be under-investment by the private sector in bio-based materials. As bio-based chemicals are important for making integrated biorefineries economical, this appears to be a policy mismatch (see further discussion below).

Bioplastics

It is expected that overall plastics consumption will grow from the current 250 000 kilotonnes a year to about 1 million kilotonnes by the end of this century. Environmental concerns regarding conventional petrochemical plastics are well known: they lack biodegradability and generate high GHG emissions in their manufacture. Also, they are often single-use, light and bulky, and create a disposal problem. In fact, plastics accumulate in the environment at a rate of 25 million tonnes a year (Ojeda *et al*., 2009). Although they are inexpensive to produce, the projected consumption rates raise economic concerns: to meet the 1 million kilotonnes market demand would require about 25% of current oil production. As easily accessed sources of crude oil become difficult to find, competition for its use increases. Therefore, the reasons to search for alternative polymers are not only environmental.

Definition

In the bioplastics field, the term bioplastic, or biopolymer, is not uniformly defined in the literature. This can cause confusion and also has practical implications, for example for labelling and for the likely carbon footprint of the material, and would be an area for policy analysis. Biopolymers are commonly regarded as biodegradable polymers. The most common definition is a combination of renewable resources and biodegradability (*e.g.* Lee *et al.*, 2003).

An example of a confusing definition is "bioplastics are either biodegradable, have bio-based content or both". When defining bioplastics, the terms biodegradable and bio-based should not be confused. A further potential source of confusion lies in the term oxo-biodegradable. The Oxo-Biodegradable Plastics Association (2010) stated that "oxo-degradation is officially defined as degradation resulting from oxidative cleavage of macromolecules, and oxo-biodegradation as degradation resulting from oxidative and cell-mediated phenomena, either simultaneously or successively". The source of these official definitions was guidance from the European Committee for Standardization (CEN) (2006).

A distinction should be made between biodegradable and bio-based. A material is considered bio-based if it, or part of the raw materials used for its manufacture, is renewable (this can be measured by standard techniques (*e.g.* ASTM D6866-10). For example, on 1 April 2011 it was announced that NatureWorks was approved to use the USDA's product label on its certified bio-based plastics under the department's BioPreferred programme. The bio-based versions of thermoplastics such as polyethylene and polypropylene have the greatest potential for market penetration. However, there is no difference in terms of biodegradability between a plastic that is a bio-polyethylene or a petrochemical polyethylene. To be biocompostable a bioplastic must biodegrade (break down into carbon dioxide, water and biomass); disintegrate (after three months of composting and subsequent sifting through a 2 mm sieve no more than 10% residue remains); and be of low eco-toxicity (the biodegradation must not produce any toxic material and the compost must sustain plant growth). It is important to recognise that compostability, which reduces the product to very small fragments, is not the same as, or as desirable as, biodegradability. Very small fragments of bioplastics tend to be chemically active, can attract other molecules and become toxic. As such they represent a danger to the environment.

Clear messages to policy makers and the general public are essential, and policy interventions need to be based on a clear, widely recognised understanding of the subject matter.

Market potential of bioplastics

Just five petro-polymers dominate the plastics market: low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polyvinyl chloride (PVC) and polyethylene terephthalate (PET) make up about two-thirds of the plastics market. Bio-based versions of some of these are beginning to be produced. The environmental credentials of some of these biopolymers come from either CO_2 capture and/or the fact that its building blocks are derived from renewable sugar rather than non-renewable oil. The genuinely biodegradable biopolymers are usually of microbial or plant origin.

Bioplastics from renewable sources, either biodegradable or non-biodegradable, were still a niche market in 2001, as their material and application development costs were far from competitive. However, in 2003 European consumption, while still a mere 40 000 tons, was double that of 2001 (Schwark, 2009). Data on the market for bioplastics are highly variable. In 2008 a number of market studies predicted that growth rates for the bio-based plastics would be 17% a year through to 2020, with significant upward growth potential. A comprehensive market survey of bioplastics (Ceresana Research, 2009) estimated that during 2000-08, worldwide consumption of biodegradable plastics based on starch, sugar, and cellulose – so far the three most important raw materials – increased by 600%.

According to a survey by Shen *et al.* (2009), the bioplastics industry expects production to grow by an average of 19% a year between 2007 and 2020 to reach production of 3.45 million tonnes annually by 2020. Current growth rates for bioplastics may be of the order of 30%; some companies are reporting 50%. Currently global bioplastics consumption is of the order of 1 000 kilotonnes, a mere 0.4% of total plastics consumption.

COPA (the Committee of Agricultural Organisation in the European Union) and COGEGA (the General Committee for Agricultural Cooperation in the European Union) have made an assessment of the potential of bioplastics in different sectors of the European economy:

- Catering products: 450 000 tonnes a year.
- Organic waste bags: 100 000 tonnes a year.
- Biodegradable mulch foils: 130 000 tonnes a year.
- Biodegradable foils for diapers 80 000 tonnes a year.
- Diapers, 100% biodegradable: 240 000 tonnes a year.
- Foil packaging: 400 000 tonnes a year.
- Vegetable packaging: 400 000 tonnes a year.
- Tyre components: 200 000 tonnes a year.
- A total of 2 million tonnes a year.

This analysis does not take into account recent developments in two large, politically powerful industries with global supply chains: automotive, with its constant need for weight and cost reduction (Pritchard, 2007), and consumer electronics (Ravenstijn, 2010).

For the bioeconomy, perhaps the most important question is the extent to which conventional petro-plastics can ultimately be replaced by bioplastics. Unsurprisingly, a definitive number is hard to find. One study (Shen *et al.,* 2009) estimated that the total *technical* maximum substitution potential of bioplastics for replacing their petrochemical counterparts was 90% of total polymers consumption (including fibres) as of 2007. The USDA has estimated that the upper limit for substitution of petrochemical plastics with bioplastics is 33%. There is however general agreement on the timescale: this will not happen in the near future.

Bioplastics and consumer electronics

Bioplastics have found uses in a variety of components of consumer electronics. They are used in connectors, PC housing, battery packages, chargers, mobile phones, portable music players and keyboards. Nokia and NEC were among the first to be involved in bioplastics, and today big industry names such as Fujitsu, Philips, Siemens and Sony are very active. Moreover, new bio-based polymers are becoming available as the demand for increased performance and new applications increases.

The thermoplastic compounder RTP Company is introducing a line of bioplastic compounds that use resins derived from renewable resources. Its bioplastic compounds contain 20-80% bio-content by weight. Prospective applications include automotive interior and industrial components, semi-durable consumer goods, and housings and enclosures for electronics or business equipment (Reinforced Plastics, 2009).

NEC has introduced a composite resin based on polylactic acid (PLA), a bioplastic, and fibres of the plant *Hibiscus cannabinus*. It is based on 90% biomass, and can be used to replace glass-reinforced polycarbonate in mobile phones (Ravenstijn, 2010). NEC was due to replace up to 10% of its polymer usage with biopolymers by the end of 2010. It has also been working on development of heat-retardant PLA composites for PC housings. In late 2009, it successfully developed and implemented a bioplastic with flame-retardant and processability characteristics that can be used in electronic devices. The new bioplastic includes more than 75% biomass components (polylactic acid, PLA) and can be produced using manufacturing and moulding processes that halve the CO_2 emissions of conventional processes used to make petrochemical-based flame-retardant plastics for use in casings for electronic goods (*www.nec.com/global/environment/featured/bioplastics/index.html*).

Sony has reported developments in flame-retardant biopolymers for products ranging from portable audio devices, home video/audio units, televisions, mobile phones, camcorders and laptop computers. The Japanese government is supportive of the incorporation of bio-based components in products. Sony is both developing new materials that are environmentally more acceptable and responding to market demand.

In 2010 Fujitsu Siemens announced it would use a bioplastic based on cellulose acetate for the keyboard of a computer product. It is also injection moulding computer keys using blends of polycarbonate and PLA.

Mitsubishi Chemical Company has a fully bio-based plastic that has been successfully developed into functional optical films for flat panel displays. A demonstration plant is under construction with plans later for a commercial plant.

A few years ago these engineering applications of bioplastics and bio-based plastics were unheard of. Innovation is driving bioplastics applications well beyond the simple packaging applications that were once the norm. Notably, durability has become an important characteristic for these bio-based engineering plastic materials. The notions of biodegradability and compostability are undesirable in such applications; recyclability and renewability are more important.

Future outlook

Various predictions of growth in the literature refer to individual segments of the overall area of bio-based product development and market penetration. Table 3.8 presents US predictions of growth across the broad range of bio-based products in the chemical sector as of 2008.

Table 3.8. World bio-based market penetration 2010-25

Chemical sector	2010 (% of market)	2025 (% of market)
Commodity chemicals	1-2	6-10
Specialty chemicals	20-25	45-50
Fine chemicals	20-25	45-50
Polymers	5-10	10-20

Source: USDA (2008). US Bio-based products market potential and projections through 2025. USDA OCE-2008-1, February.

The manifestly different approaches of the United States and EU reflected differences in objectives. In the United States the central issue was energy security. The bio-based economy was declared a national security issue and was driven top-down by government. The Biomass Research and Development Act (2000) set out directions for national energy and agricultural policies to reduce dependence on imported petroleum. This has resulted in massive public spending on research. The results are there to see. The EU approach was based on keeping the EU chemicals sector competitive.

However, the US biofuels strategy has not meant that the chemicals sector has been ignored. Many milestone achievements have been made, *e.g.* Sorona, 1,3-PDO. The developments in chemicals have given the United States a head start, especially in intellectual property, and the potential to outcompete foreign economies.

The Asian chemical industry as a whole has overtaken the EU in terms of sales. The use of biofuels as transport fuel has good prospects in developing countries, most of which face severe energy insecurity and have large agricultural sectors to support production of biofuels from energy crops (Liaquat *et al.*, 2010).

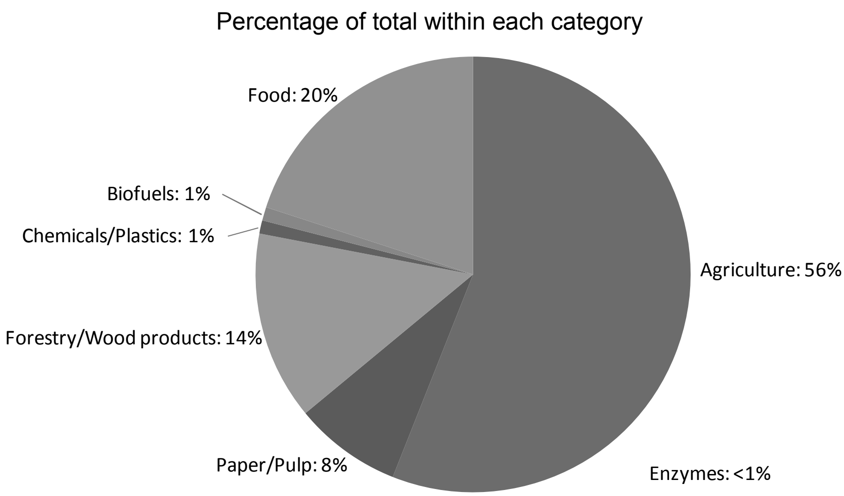
Green jobs

Every new job in the US chemicals industry can lead to 5.5 additional jobs elsewhere in the economy (Bang *et al.,* 2009). This, and recent US biorefinery openings, demonstrate that the current US bio-based products industry is already responsible for more than 40 000 American jobs (Biotechnology Industry Organization, 2010). Federal policy in the United States in support of biofuels has resulted in an additional 240 000 jobs and contributed USD 65 billion to GDP in 2008 (Carr *et al.,* 2010). The Brazilian ethanol programme provided nearly 1 million jobs in 2007, and cut 1975-2002 oil imports by a cumulative undiscounted total of USD 50 billion (Wonglimpiyarat, 2010).

Less than 4% of US chemical sales are bio-based. However, the USDA has projected a potential market share in excess of 20% by 2025 (USDA, 2008). If that growth rate can be achieved and sustained, it would create or save tens of thousands of additional jobs, even in the near term (Industrial Biotechnology, 2010b, Industry Report). Many jobs in the petrochemicals industry have been lost in OECD countries as the industry moved to be closer to the feedstock sources.

In the EU the integrated bioeconomy of 2009 was already worth EUR 2 trillion annually and employs over 21.5 million people (BECOTEPS, 2011). The breakdown of these jobs is instructive from the industrial biotechnology perspective (Figure 3.7).

Figure 3.7. Breakdown of jobs in the EU bioeconomy, 2009



Source: Adapted from BECOTEPS (2011). The European bioeconomy in 2030: Delivering sustainable growth by addressing the grand societal challenges. White paper of BECOTEPS (Bio-Economy Technology Platforms), an EU Framework 7 programme.

Quite clearly, industrial biotechnology still plays a relatively minor role in bioeconomy jobs in Europe. Jobs in enzymes play a small role, although Europe has a clear world lead in this sector, as some 70% of industrial enzymes originate in Europe (Potočnik, 2008).

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