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Biobased Chemicals and Bioplastics

FINDING THE RIGHT POLICY BALANCE

OECD



FOREWORD

Bio-based production is widely viewed as a central manufacturing element of the next bioeconomy. Bio-based products can be classified as biofuels, bio-based chemicals and bio-based plastics (with the latter two generally grouped together as bio-based materials). The earliest years of the 21st century saw an explosion in interest globally in biofuels production, with food crops generally comprising the raw biomass material. The focus on biofuels has since moved to second generation, or cellulosic, biofuels. A great deal of effort has gone into perfecting the processes for cellulosic biofuels, and the fruits of this labour are just emerging. However, producing biofuels at the scale required to influence markets has proved extremely challenging.

It has long been known in the conventional oil and petrochemicals industries that many chemicals have much more attractive margins than fuels, with the latter margins often hovering around zero or less. Moreover, chemicals are produced in much smaller volumes than fuels. The recent trend globally in the oil industry has been to integrate fuels and chemicals production at massive complexes to take advantage of the greater profitability of chemicals. There is no reason to suspect that mature bio-based production will be different. Integrated biorefining has been the focus of much research effort and now there is a palpable shift in emphasis in the industry towards bio-based chemicals.

On the policy front, it has been obvious for several years that there is a vast network of public policy support mechanisms for biofuels, involving subsidies across the entire value chain from biomass to by-products of the production process. The recent boom in bioenergy, involving the use of wood pellets to fuel power stations, has also benefited from a great deal of policy support. In comparison, the support given to bio-based chemicals and plastics has been minimal. This makes policy geared towards integrated biorefining unbalanced. This report examines the reasons why governments may wish to look at this policy imbalance and consider whether it needs to be redressed. Lines of evidence are presented and potential solutions are offered.

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EXECUTIVE SUMMARY

Policy goals relating to grand challenges such as climate change, energy security, food security and the rising human population, topped by the worst economic recession in decades, have accelerated the call for economic growth that can be achieved without environmental damage. A projected doubling of global wealth is estimated to increase greenhouse gas (GHG) emissions by 80%.[1] The notions of green growth and a future bioeconomy envisage de-coupling this relationship.

As OECD countries emerge from the global financial crisis, several countries have published their plans for the development of a future bioeconomy, an economy in which bio-based materials and production techniques will contribute significantly to economic and environmental sustainability. Such plans typically involve building a bio-based production industry in which fuels, energy and materials such as chemicals and plastics, usually generated from fossil resources such as oil and natural gas, are incrementally replaced by equivalent or novel products generated from renewable resources. The realisation of this vision will require sustainably harnessing the vast biomass resource.

In light of growing concerns over climate change, many countries have already started to identify ways to decrease their dependence on fossil fuels for electricity, heating and transport fuels and to implement related policies. In the first decade of this century, there was an enormous expansion in the production of biofuels, principally bioethanol and biodiesel. Equally, there has been an explosion in interest in the generation of electricity from renewable resources, especially from products of forestry such as wood pellets. Over 70 countries now have bioenergy targets and at least 109 offer some level of policy support.

Research efforts in biofuels production have grown recently, leading to the concept of the integrated biorefinery. The integrated biorefinery would, as in the case of integrated oil refineries, see the production of fuels and chemicals and plastics at the same production complex. Indeed, research interest in the production of chemicals from biomass to substitute for fossil-derived chemicals goes back at least several decades. But, as long as oil was cheap and plentiful, bio-based chemicals production on a large scale could not be imagined. Rising concerns over the grand challenges (e.g. climate change, sustainable growth) and the potential of oil price spikes and the emergence of the integrated biorefinery concept have begun to rekindle interest. Linked to recent progress in synthetic biology, research into bio-based materials production (in this context, for chemicals and plastics) has opened up the possibilities of replacing many more fossil-derived chemicals and plastics than was previously foreseen.

The costs of research are much lower than the costs of commercial-scale production. Bioelectricity and biofuels have reached the market in part as a result of substantial public investment in the form of various supportive policy incentives, without which their future would have been uncertain and their use much delayed. What started out as policy support in a tiny nucleus of countries has burgeoned very rapidly. Now over 50 countries have targets in place for biofuels production and many of these countries are also using public support to bring these products to the market. The types of policies used are diverse and span the value chain from agricultural subsidies all the way through to market readying measures and infrastructure development. The policies have inevitably had a knock-on effect in other sectors. For example, the automotive industry has been required to start producing flex-fuel vehicles (FFV) able to run on blends of ethanol and petrol.

Whilst progress in bioelectricity and biofuels production is palpable, decades of research efforts into bio-based chemicals and plastics production have not led to similar commercial progress. This is not a constraint due to lack of technical know-how. Rather, bio-based materials production has not received the

policy attention necessary for biochemicals to start to substitute for petrochemicals (and therefore potentially to bring about GHG emissions and help governments meet their climate change obligations). In the United States, however, greater support for bio-based materials has started to emerge. For example, in the Farm Bill of 2014, Program 9003, the USDA "Biorefinery Assistance Program" was renamed the "Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program". The USDA was directed to ensure diversity in the types of projects approved and to cap the funds used for loan guarantees to promote bio-based product manufacturing at 15% of the total available mandatory funds. The important point to note, however, is that the same policy mechanism is now being used to support both biofuels and bio-based products and materials.

In addition, the rapid growth in bioelectricity and biofuels production has seen the creation of policies that favour the acquisition of large quantities of sustainable biomass. This has led to a situation where biomass is being systematically allocated to these sectors, not to the production of bio-based materials. In particular, the recent rise in trade of wood pellets for renewable electricity generation is starting to increase substantially the cost of pellets. The market is not constrained by demand, but by the supply of sustainable biomass. Due to supportive policies for bioenergy, biomass is available for electricity applications at prices that are lower than those for bio-based materials applications. This also counteracts the idea of cascading use of biomass.

This report examines the reasons why governments may wish to look at their policy balance and consider treating bio-based materials production similarly to fuels and electricity applications. The lines of evidence are:

- Later this century, a situation may arise where continuingly increasing demand for chemicals and plastics may cause them to start to compete with fuels for available crude oil. The price of crude oil is predicted to rise as it becomes more difficult to find in high quality forms in locations that make its production safe and inexpensive. In addition, climate research suggests that much of the existing inventory of hydrocarbons should not be burned if global warming is to be limited to 2ºC.

- The trend in the oil and petrochemicals industries is towards increasing levels of integration i.e. many different products coming from the same complex. Margins on fuel production have dropped and OECD countries have already seen many refinery closures. Capacity building in Asia and the Middle East may reduce margins further, resulting in further closures, especially in Europe. Integration increases refinery profitability as higher value-added chemicals are produced, with higher associated margins. This same economic dynamic could potentially be replicated in bio-based production. Indeed, the production of bio-based materials alongside biofuels may be necessary to make biorefineries viable.

- Many studies have shown that bio-based chemicals and plastics have significant environmental performance advantages over petrochemicals, especially with respect to GHG emissions. Many countries are experiencing difficulty in achieving their climate change targets. Substituting petrochemical for bio-based production seems to offer part of the solution.

- Biofuels production has been linked with food price spikes in recent years in the context that, at mass scales, the harvesting of the necessary biofuel raw materials puts pressure on land availability, thereby bringing it into competition with the use of land for food and feed production. Since the production volumes for chemicals and plastics are much smaller than for fuels, the production of bio-based materials would require less land. In addition, better land area efficiency can be achieved for biochemicals compared to biofuels.

- Rural regeneration and job creation are high priorities in strategies for bio-based production and the bioeconomy. Evidence from several sources suggests that bio-based materials production creates many more jobs and more value-added than either biofuels or bioelectricity. A recent European estimate emphasises the point: in 2011, there were roughly 150 000 jobs in Europe in each of bio-based materials and biofuels production. However, the turnover from biofuels production was EUR 6 billion, whilst the turnover from bio-based materials, with the same number of jobs, was estimated to be EUR 50 billion, more than eight times higher than for biofuels.

- There is speculation about the potential impacts on bio-based production of harnessing of shale gas, and future developments with gas hydrates. The shift towards gas feedstocks is already driving up prices of aromatics and C4 chemicals such as butanediol and butadiene. Propylene prices could rise dramatically as a result of limited co-production of olefins in gas-fed ethylene crackers. As gas crackers increase in popularity, naphtha crackers are already closing or downsizing. Given the positive and negative effects that may occur, the question of which bio-based chemicals will succeed on a large scale is likely to depend more on technology advances, availability of funding and market pull than on developments related to shale gas.

Policy options to support bio-based materials have been broadly divided into two categories in this report:

1. Balancing policies for fuels, electricity and bio-based chemicals and reducing the competition for biomass;

2. Addressing policy gaps throughout the value chain.

Bio-based production differs somewhat from many other technology-related developments in the length and complexity of its supply chains. In particular, bio-based production policy interacts with agricultural policy, which is notoriously complex. It is necessary for governments to be cognisant of these complex interactions. A holistic approach to policy is more likely to lead to a successful bioeconomy, with governments avoiding creating policies in one area that may create policy problems elsewhere.

Any attempt to implement a policy balance that places biochemical policies on a par with biofuels and bioenergy should be done in a way that minimises the cost to the taxpayer. One option is to apply the policy support measures that are currently available to biofuels and bioelectricity to bio-based materials. Utilising existing support mechanisms in this way would avoid the need to create entirely new administrative systems.

However, many of the policy measures for biofuels and bioelectricity are not applicable to bio-based materials. For example, feed-in tariffs for bioelectricity fed into a grid system would not be applicable to materials. The chemicals and plastics markets are also much more diverse than electricity. Nonetheless, some major policies that have been applied to biofuels may be applicable to biomaterials, the most significant being:

- Quotas/mandates;
- Tax incentives;
- Market readying measures such as public procurement; and
- Regulatory policies.

The major policies that are most likely to stimulate investment in bio-based materials are quotas/mandates and tax incentives. Public procurement acts as a demand-side measure to stimulate market uptake.

Another, potentially very effective, measure would be a planned phasing out of fossil fuel consumption subsidies. Policies supporting biofuels production have been blamed for creating market distortions. However, large fossil fuel consumption subsidies in developing economies (totalling over half a trillion USD in 2011) distort the fossil fuels market. In OECD countries, over 550 fossil fuel consumption subsidies have been identified,[2] resulting in the loss of USD 55-90 billion annually to those governments. As many of these countries are already struggling to meet their climate change obligations, it is argued that phasing out wasteful fossil fuel consumption subsidies could generate the finance to help meet these obligations, potentially at no cost to taxpayers.

This needs to be complemented with an effective system of carbon pricing. Carbon taxes have the advantage of directly taxing carbon, and therefore can help in transparently achieving policy goals efficiently in a way that mandates may not. While the carbon tax has not been popular politically, nine OECD countries have introduced carbon taxes since Sweden did so in 1991, suggesting there is some hope for the future.

Regulatory regimes impact the bio-based chemicals sector more than they impact the petrochemicals sector. Complex and time-consuming regulation is far more damaging to small bio-based companies than it is for large petrochemical companies. Governments could act to reduce this impact. Concerning the bioeconomy more broadly, a report from the Netherlands identified 70 regulatory barriers to the development of a European bioeconomy, of which 24 could be overcome without legal intervention.[3]

Many of the policy gaps for bio-based chemicals relate more widely to the bioeconomy as a whole. For example, building demonstrator plants that can process different types of biomass (in particular lignocellulosic and organic waste) and produce several products including fuels and chemicals/plastics are relevant across the bioeconomy. In these early days for bioeconomy strategies, policy needs can be difficult to foresee. This report therefore identifies broad issues, rather than focusing on fine detail. The policy goals of bioeconomy strategies could include:

- Construction of infrastructure, especially demonstrator plants. However, bioeconomy plans often envisage using rural locations for such plants in order to ensure that the biorefineries are close to the biomass, and also to generate rural jobs. Governments would therefore need to look closely at rural infrastructures e.g. road and rail networks, electricity supply. It may be expedient to choose rural locations that are well serviced by infrastructure to minimise the cost of public intervention. One way of stimulating large-scale investment by the private sector is to leverage public investment through public-private partnerships (PPPs). However, other innovative measures are also starting to be used, such as green investment banks;

- The need for an educated workforce and the related need to provide appropriate skills/training have already been identified as potential roadblocks to a bioeconomy. It could be argued that these are most acute in bio-based materials production, where biotechnology interfaces with chemistry and engineering. Entrepreneurial and business skills also have to be woven into bioeconomy education. Several approaches are suggested. The availability of skilled people who have lost their jobs through the closure of OECD country oil refineries could help to alleviate this problem. Many of the skills of oil refining are very similar to those of biorefining. Retraining these skilled workers could reduce migration to the Middle East, where such skills are in demand;

- Market readying and introduction measures have already started in some countries. The power of public purchasing is high and this can quickly facilitate market introduction. Currently there is no harmonised system of economic, environmental and social performance assessment for bio-based chemicals. Even environmental performance assessment is ambiguous due to lack of standardisation of life cycle analysis (LCA) procedures. Development of a standardised system of assessment could contribute to market readying;

- Labelling is one way of gaining consumer confidence, provided that unambiguous standards are used to avoid confusion and accidental misguidance of the consumer. More broadly, public information programmes can help the public to understand why bio-based materials are being introduced and, more broadly still, what the bioeconomy can mean for the future. Such programmes could be tailored to the audience: farmers require different information from the purchasing public, for example;

- Many of the companies involved in bio-based materials research are very small; some are even micro-enterprises. In a market dominated by petrochemicals, their existence often remains precarious for many years. Specific SME support mechanisms could be introduced to make their existence easier, allowing them to focus on core skills related to innovation.

Much of the evidence gathered for this report points to a future bioeconomy in which bio-based chemicals and plastics play a central role. Many of the biofuels currently being researched and produced will only be transition fuels if electric mass and freight transportation systems and small electric vehicles are perfected. At some time in the future, biofuels may occupy niche markets, such as shipping and aviation. At that point, the demand for chemicals and plastics will continue to increase, potentially placing severe strain on crude oil to meet demand. Applying relatively simple and inexpensive policy measures to support the development of bio-based materials production now may head off large problems in the future.

Current priorities include: allowing bio-based materials to compete for biomass on price with bioelectricity and biofuels; rectifying the market distortions caused by fossil fuel subsidies; heading off future competition for crude oil demand; and correcting for any excessive regulatory impacts. If governments wish to realise a successful bioeconomy in the future, the case for supporting the production of bio-based chemicals and plastics warrants serious attention.

INTRODUCTION

When the policy regimes across the bio-based industries are analysed, bio-based materials (in general, bio-based chemicals and plastics) are found to be at a relative disadvantage compared to liquid biofuels. In addition, the global upsurge in bioenergy applications, in particular burning wood chips in power plants, has led to governments introducing supportive policy measures. The bioenergy and biofuels sub-sectors use very high volumes of biomass as feedstock and address crucial energy security and climate change issues, the strongest political drivers for bio-based production. However, they are not the only important uses of biomass, one other being the production of bio-based materials, most significantly bio-based chemicals and bioplastics. This report seeks to show that there are grounds for reconsidering the policy balance for the bio-based sectors. It illustrates some policy approaches that could be used as support for the bio-based sectors, removing any current barriers to the use of biomass for wider applications than biofuels.

To illustrate the current policy situation, it is informative to look at the United States. Of all the United States federal funding for R&D in biomass and bioenergy since the 1970s, as much as 70% has gone to biofuels, according to the US Department of Energy (DOE) (Waltz, 2008). In the United States *Food, Conservation, and Energy Act* of 2008[4] (the *Farm Bill*), more than USD 1 billion was provided for advanced biofuels, whereas bio-based materials received USD 9 million, over a five year period. Yet the potential business opportunities for bio-based chemicals are huge. Ninety-six per cent of all manufactured goods in the United States use some sort of chemical product and businesses dependent on the chemical industry account for nearly USD 3.6 trillion in US GDP (Milken Institute, 2013).

The *Farm Bill* supported biofuels through many forms of incentive: loan guarantees for the construction of next-generation biofuels plants, funding for conversion technologies to break down plant matter, support for R&D in feedstock development and cellulosic biofuels production efficiency, as well as payments to farmers near biorefineries to help them make the transition to dedicated energy crops. The other, non-fuel bio-based products were supported only through a rule that requires federal agencies to give purchasing preference in its contracts to bio-based products and through an expansion of the products that qualify.

Additionally, the *Energy Independence and Security Act*[5] (EISA) (2007) through the Renewable Fuels Standard (RFS2) (Federal Register, 2010) set high production volume mandates for biofuels. Together with blending mandates, a comprehensive policy support regime for biofuels came into being in the 21st century in the United States.

The situation is almost the same in Europe, but perhaps not quite as strong as in the United States. The European Community (EC) Directive 2009/28/EC[6] (the *Renewable Energy Directive*) is part of a package of energy and climate change legislation that provides a legislative framework for EC targets for greenhouse gas emission savings. It set mandatory national targets consistent with a 20% share of energy from renewable sources and a 10% share of energy from renewable sources in transport in the EC by 2020.[7] There has been a wave of investment in biofuels because of these targets. Moreover, many European countries are looking to bioenergy applications to address energy security and climate change policy objectives. This has led to a dramatic increase in the importation and use of wood pellets to Europe for electricity generation in a short time period. Biomass prices have risen significantly, with consequences for the emerging bio-based chemicals and plastics industry, but also for more established sectors of the bioeconomy, such as the particle board and oriented strand board (OSB) industries.

Now, many other countries 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). According to the Global Renewable

Fuels Alliance (a global biofuels federation representing over 65% of the world's renewable fuels production from 44 different countries), 62 countries now have biofuels-friendly policies in place whose ethanol production alone has replaced the need for over 2 million barrels of crude oil per day.

Similarly, biofuels have proven a particular draw for venture capital investors. A very clear reason for this is that the market for fuels dwarfs that of chemical and materials markets. In most countries well over 90% of crude oil and natural gas is used for energy purposes. Meanwhile, the standards applied to fuels are simpler and much less numerous than those applied to chemicals. The chemicals markets are more controlled and more difficult to penetrate. Customer acceptance criteria are harder to predict than for fuels (Waltz, 2008). The public expectation of a fuel is very simple. For plastics, the expectations are very varied, depending on the application (compare the expectations for, say, a vehicle radiator with a film wrap for food).

Yet biofuels and bio-based chemicals and plastics have several compelling commonalities. They are often made from the same raw materials (biomass). Their futures depend on the success of the same emerging conversion technologies for lignocellulosic feedstocks. Their competitiveness in the market is dependent on crude oil prices. They share some of the same manufacturers. They can be, and are perhaps most efficiently, produced at the same facility. In fact, a number of studies have shown that co-ordinating bio-based fuel and chemical production - the integrated biorefinery concept - can achieve efficiencies (Kamm et al., 2006).

UNEP (2010) calculated that a doubling of wealth leads to an 80% increase in emissions. At the heart of the OECD publication, *The Bioeconomy to 2030: Designing a Policy Agenda* (2009), is the need to decouple economic growth from environmental degradation, in particular the need to drastically cut greenhouse gas (GHG) emissions. That same publication envisages a future bioeconomy in which biotechnology could be responsible for 2.7% of GDP in OECD countries, this number excluding the potential of biofuels. It goes on to predict that, well before 2030, biotechnology will be used in the development of all pharmaceuticals and most new varieties of large market crops. Since its publication, several countries and regions have responded with bioeconomy strategies, among them Canada, Denmark Finland, Germany, Ireland, the Netherlands, Norway, Sweden, the United States, the European Union and South Africa[8] many foreseeing a gradual replacement of fossil-derived materials with bio-based.

The recent publication of bioeconomy strategies by various nations and regions makes the case for bio-based production industries that cover biofuels, bio-based chemicals and bio-based plastics. The following (adapted) text from the European Union (European Commission, 2012) is illustrative:

> "*Significant growth is expected to arise from sustainable primary production…and industrial biotechnology and biorefineries, which lead to new bio-based industries, transform existing ones, and open new markets for bio-based products*."

Also in 2012, the United States government released its National Bioeconomy Blueprint, which envisaged "*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).

Central to this paper is the contradiction between these expectations and actual spending in industrial biotechnology R&D to achieve them, as identified in *The Bioeconomy to 2030: Designing a Policy Agenda* (2009), see Table 1.

Table 1. R&D expenditures versus future markets for biotechnology by application

	Share of total OECD business expenditures on biotech R&D in 2003 (%)	Estimated potential share of total biotech gross value added (GVA) in the OECD area for 2030 (%)
Health	87	25
Primary production	4	36
Industry	2	39
Other	7	-

Source: The Bioeconomy to 2030: Designing a Policy Agenda (2009)

The vast majority (87%) of private sector biotechnology R&D spending in 2003 went to health applications, with just 2% going to industrial applications. For industrial biotechnology to deliver the 39% of expected GVA by 2030, substantial changes are required. Such is the gulf between reality and expectations that it would be necessary for governments to encourage a steep ramping up of spending on industrial biotechnology. The beginnings of this change have been seen, but with the focus almost entirely on biofuels.

Whilst there is a highly evolved and supportive policy regime relating to liquid biofuels (and also to other bioenergy applications), this is not the case for bio-based chemicals and plastics. This has been much discussed at many events (e.g. Friends of Europe, 2012) and several reasons have been proposed for a rebalancing of policy supports, among them:

- Bio-based chemicals and plastics have longer value chains than biofuels, and may support more jobs as a result;
- Bio-based plastics and chemicals, especially the latter, are likely to command higher margins in the long-term compared to biofuels, which could make the difference between viability and the closure of biorefineries;
- Some of the significant concerns resulting from mass production of biofuels, in particular indirect land use change (ILUC), need not apply to bio-based chemicals and plastics, largely due to much smaller production volumes;
- The huge demand for biomass created by biofuels and bioenergy may lead to a situation where bio-based chemicals and plastics cannot compete for biomass on price;
- The efficiencies that may be achieved through integrated biorefining may not be possible without governmental support for bio-based chemicals and plastics.

Bio-based chemicals and plastics appear to offer benefits in environmental (e.g. GHG emissions savings), social (e.g. new jobs, and some of these in the rural environment) and economic terms (e.g. value-added, cascading utilisation of biomass) – the so-called *triple bottom line*.

The next section explores why governments may need to reconsider the current balance of policy support measures.

EVIDENCE BASE FOR A RECONSIDERATION OF THE BALANCE OF POLICIES BETWEEN ENERGY, FUEL AND MATERIAL USES

"*But focusing on the next 5 years, I would like to see us be able to produce any chemical we now get from petroleum, but from a renewable feedstock. I think that is a big challenge, but I think we're up to it. Innovations in how you design enzymes and translate that into producing replacements in petroleum-based products is something we could achieve in the next 5 years*".

Source: A conversation with Jay Keasling, 2013 (Industrial Biotechnology Interview, August 2013)

The major policy goals of bio-based production are high up on political agendas as some of them address global grand challenges. For many governments, the most pressing of these is energy security, but nowadays climate change mitigation and energy security have become inter-linked policy goals due to increasing evidence for, and greater acceptance of, climate change. Energy security has also become entwined with food security, which then involves water security. Others include rural regeneration and job creation. For Europe, with a global lead in chemicals production, but one that is threatened by the rise of the Asian and Middle Eastern chemical industries, another policy goal is keeping European chemicals production competitive.

In this section, the policy goals of bio-based production, and the evidence for increased importance being paid to bio-based chemicals and plastics production, is investigated.

Energy security

The International Monetary Fund (IMF) has calculated that a 10% rise in oil prices removes 0.2-0.3% from global GDP growth in the first year, but the impact on a big oil consumer, such as the United States, is twice as large (*The Economist*, 2011). High prices and oil shocks have contributed significantly to historical recessions (Jones et al., 2004): Hamilton (2011) stated that 10 of the 11 post-war US recessions have been preceded by a sharp increase in the price of crude oil. Based on evidence from some European countries, Cuñado & Pérez de Gracia (2003) suggested that oil prices have permanent effects on inflation.

Many of the OECD countries are net importers of crude oil and natural gas, especially in the European Union, where there are only a few oil producers and exporters. Hungary, for example, imports 80% of its domestic crude oil requirements, and this percentage may increase (National Renewable Energy Action Plan 2010-2020, 2010). Oil production in the United Kingdom and Norway has been falling steadily in recent years following peak production in 1999 and 2001 respectively. The United Kingdom has recently become a net oil importer (OilPrice.com, 2010).

Some Asian countries typify the energy security dilemma. Thailand has to finance growth but is highly dependent on crude oil imports, which account for more than 10% of GDP (Siriwardhana et al., 2009). Energy security and rural and economic development drove Malaysian R&D on biodiesel derived from palm oil as early as 1982. Since the oil crises of the 1970s, the Japanese government has embarked on national projects in developing alternative energy resources with the purpose of raising the productivity of bioethanol production. Korea has similar needs. Likewise, China has a huge demand for crude oil that cannot be met through domestic production. However, as an agricultural country, China cannot sacrifice food security for energy. Currently, India has turned to bio-based energy to reduce dependence on imported oils. India has to import approaching 80% of its crude oil requirements (Ministry of Petroleum and Natural Gas, Government of India, 2009). India leads the way in planting and cultivating the non-food Jatropha plant on an industrial scale for biodiesel production (Wonglimpiyarat, 2010).

No country illustrates the situation better than Japan, the world's third largest economy, which is only 16% energy self-sufficient.[9] Japan is the world's largest importer of liquefied natural gas (LNG), second largest importer of coal and the third largest net importer of oil. Japan relied on oil imports to meet about 42% of its energy needs in 2010 and to feed its vast oil refining capacity (some 4.7 million barrels per day at 30 facilities as of 2011), and relies on LNG imports for virtually all of its natural gas demand. Japan consumed an estimated 4.5 million barrels per day of oil in 2011, whilst it produced only about only 5 000 barrels per day.

Many countries have looked to biofuels as a component of their future energy security strategies, having 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). In 2012, the Biofuels Digest released its annual review of biofuels mandates,[10] stating that there were 52 countries with mandates or targets, mostly in the EU, but also 13 in the Americas, 12 in Asia-Pacific and 8 in Africa. So clearly, energy security is a global issue and an issue with serious consequences for the future of Asia.

There is plenty of crude oil but little spare capacity

Currently there is very little spare capacity in crude oil production, and the capacity that exists resides in the Middle East, not in OECD countries. New oil discoveries globally have not kept up with annual production since at least 1980. In 2008, the International Energy Agency (IEA) significantly amended its prediction of the decline of conventional oil production, from 3.7% per year to 6.7% per year (IEA, 2008).

> "*Out of the turmoil of the energy markets of the last 12 months and our evaluation of future influences on the sector has emerged a new underlying price assumption for the World Energy Outlook — an oil price through to 2030 which nudges twice the level in WEO-2007. The era of cheap oil is over*."

Source: IEA World Energy Outlook (2008)

Owen et al. (2010) supported the contention held by many independent institutions that conventional oil production may soon go into decline and it is likely that the "*era of plentiful, low cost petroleum is coming to an end*."

The deep oceans will provide further significant crude oil discoveries, but these discoveries come with various price tags – the actual cost of extracting oil from deep-water locations, and environmental and increasing safety concerns and costs (e.g. Noble et al., 2013; Rochette, 2012). Offshore oil exploitation is moving into increasingly deep waters (over 2 kilometres today, compared to around 10 metres in the 1940s), and several recent high-profile accidents have raised public awareness of the problems.

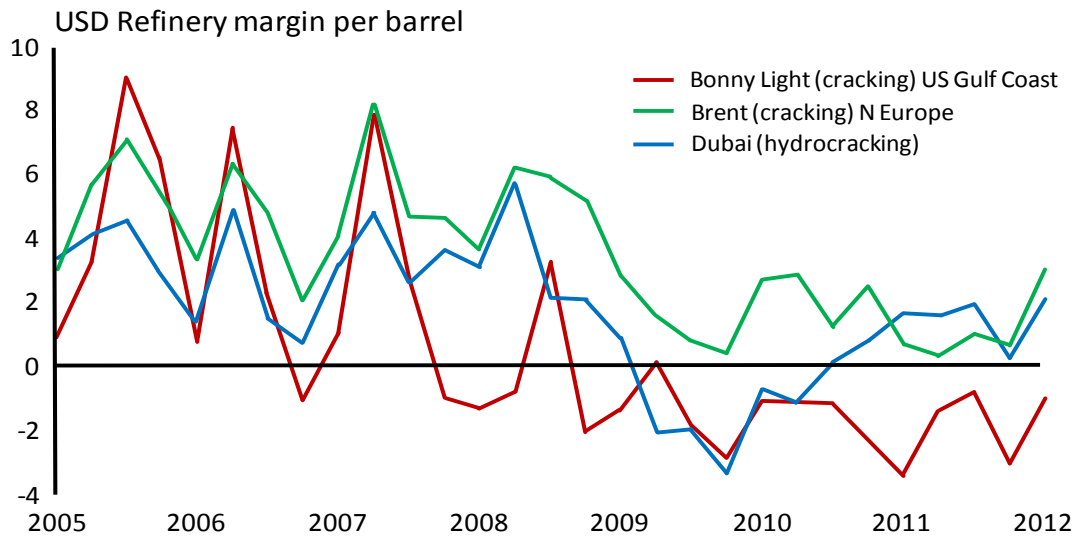
Given the increasing world population, the demands on conventional oil mean that the industry will simply not be able to cope. Supply has not significantly increased in recent years, while demand has considerably increased (world demand grew by a huge 2.7 million barrels per day in 2010) (OECD, 2011c), and unconventional oil sources have problems, including price, environmental sensitivity and technical production problems.

Integrated biorefining: lessons from the economics of oil refining

Parallels with the downstream part of the oil industry, specifically with the economics of fuel production from crude oil, suggest there is a case for policy support for bio-based chemicals and plastics, or at least for creating a better policy balance with liquid biofuels. Despite recent high prices of crude oil, the margins in the production of petrol and diesel are extremely small (Figure 1), and profitability is at the

whim of crude oil prices. This is one of the reasons for integration i.e. the integration of fuel and petrochemical production at the same site, and increasingly in locations close to the feedstock (crude oil).

Figure 1. Oil refinery margins



Source: AT Kearney (2012)

Current refining capacity building in the Middle East and Asia, with lower operating costs, means that refiners in the OECD countries will face greater difficulties as margins are squeezed even further. Non-OECD economies are already home to over half of the global refining capacity, with that share only expected to grow (IEA, 2013). In the next five years, virtually all net crude distillation capacity growth is forecast to take place in the emerging market and developing economies. Combined with lack of demand during the economic crisis, OECD countries experienced a round of refinery closures.

Europe has been hit particularly hard by loss of refining capacity (Table 2). Fifteen European refineries have shut down since 2008, while many others are running at reduced capacity. The biggest loss in Europe between 2008 and 2012 was suffered by France, which lost 25%. Germany lost 12% in the same period, compared with 11% in the UK and 8% in Italy. The recent closure of the Coryton refinery in Essex, with the loss of some 850 jobs,[11] may be a portent of things to come. There are now seven refineries in the United Kingdom, down from 18 in the 1970s. Security of energy supply is one of the principal policies at the United Kingdom Department of Energy[12]. A new round of oil refinery closures in OECD countries is a distinct possibility, especially in Europe. Meanwhile, Sinopec, Asia's largest oil refiner, posted a 24% increase in profits for the period January to June 2013.[13] China's other refining giants also posted large profits for the period.

Table 2. Recent losses in European oil refining capacity

Country	Refinery	Status	Period
Belgium	Antwerp	Restarted	Mid-May 2012
Czech Rep.	Paramo	Permanent closure	May 2012
France	Petit Couronne	Temporary restart	mid-June 2012
	Berre l'Etang	Permanent closure	Jan 2012
Germany	Ingolstadt	To restart	Q4 2012
	Hamburg	Permanent closure / storage	Q2 2012
Italy	Gela	12 month closure	Jun 2012-Jun 2013
	Rome	Permanent closure / storage	Q3 2012
	Falconara	12 month closure	Jan-Dec 2013
Romania	Arpechim	Permanent closure	Jan 2012
Switzerland	Cressier	To restart	Jul-Aug 2012
UK	Coryton	Permanent closure / storage	Jul 2012
Ukraine	Lisichansk	Indefinite closure	Mar 2012

Source: www.platts.com/latest-news/oil/London/FACTBOX-European-refinery-closures-permanent-3190022

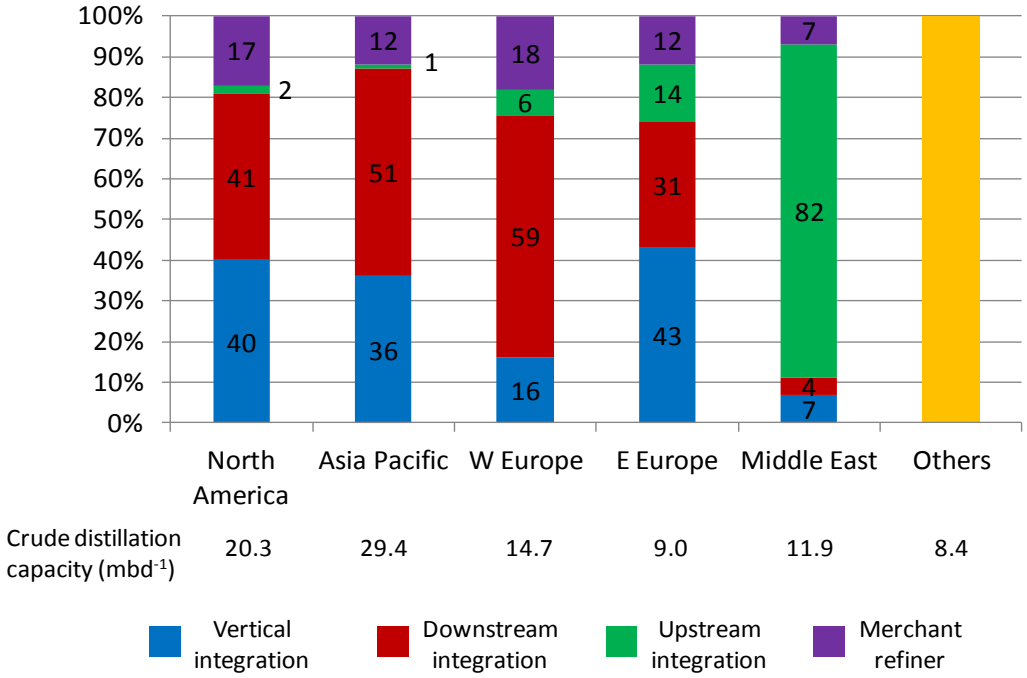
A recent KPMG report (KPMG Global Energy Institute, 2012) predicted that this time many of the changes being experienced in European refining are likely to prove permanent. The current trends of falling demand, rising imports, increasing European legislation, growing competition from emerging markets and eroding margins are likely to continue.

Will the same market dynamics apply to bio-based production?

The market dynamics for bio-based production in the future are likely to be similar to those for oil refining if biofuels are produced in very large production volumes with minimal profit margins. There has been much debate about integrated biorefining, but the policy gap between biofuels and bio-based materials means that it is likely that a competition for biomass will be won by biofuels if bio-based materials do not qualify for incentives, which will impact potential biorefinery operations.

There has been a clear trend in the oil industry towards integration to make fuels and chemicals at the same site. Various forms of integration can be described (Figure 2), with much the same goal – the integration of low value fuels with higher value chemicals and plastics. The largest of the Middle Eastern companies, Saudi Aramco, has long had a consistent strategy of vertical integration (Kobayashi, 2007) with a view to integrating refineries with petrochemical facilities, to create an "economic multiplier effect".

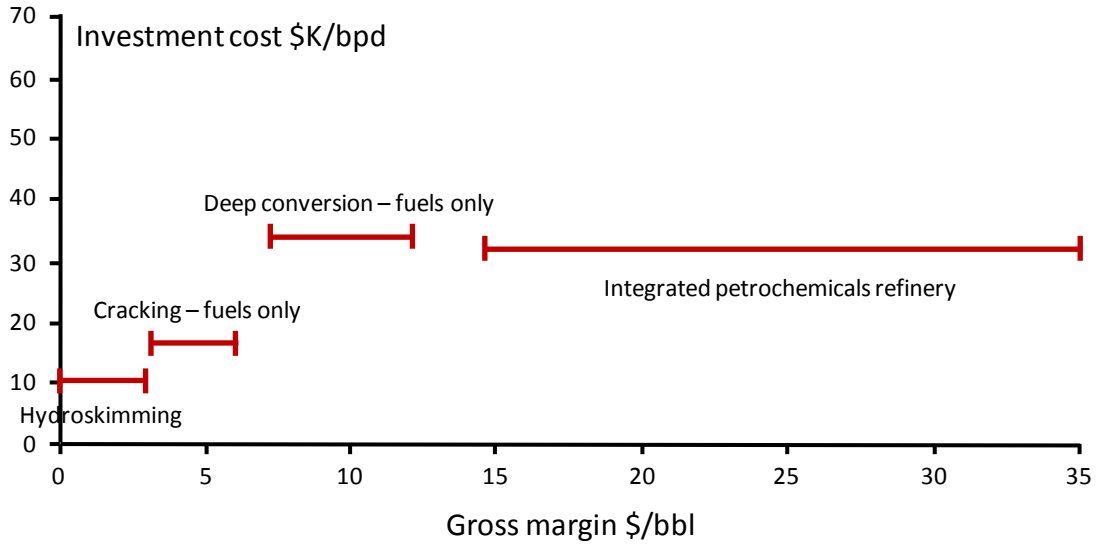
Figure 2. The trend towards integration within the oil industry[14]



Source: ATKearney (2012)

The reasons for this trend towards integration become clear when the economics of various production scenarios are examined (Figure 3). It should be borne in mind that most plants are fully amortised, and operate at highly optimised economies of scale. The best margins are clearly from petrochemical integration.

Figure 3. Crude oil refinery economics



Source: Cook (2009)

In the integrated fuels and petrochemicals model, chemical and fuel production are integrated within a single operation. In such an operation, high value products become an economic driver providing higher margins to support low value fuel, leading to a profitable biorefinery operation that also exhibits an energy impact. This is how many petrochemical oil refineries are operated – the 7-8% of crude oil dedicated to chemical production results in 25 to 35% of the annual profits of integrated petrochemical refineries (Bozell, 2008). Despite the high profits that often are available in the upstream oil industry, the downstream production of transport fuels often work on very poor margins indeed. These same market dynamics may be expected with biofuels being produced in high volumes.

An integrated biorefinery is obviously technically very complex, even more so than a petrochemical facility, but there are at least three significant advantages compared to mono-substrate, mono-product biorefineries:

1. The ability to switch between feedstocks and products when, for example, one particular feedstock is too expensive;
2. Integration facilitates cascading use of biomass, a method considered to achieve optimal efficiency of biomass use (Box 1);
3. The production of higher-value products, thereby avoiding the low-margins business of producing only high volume fuels.

Consider a recent situation in United States biodiesel production from soybean oil. Between 2005 and 2008, the price of soybeans doubled. Many biodiesel production plants halted production,[15] and construction of new plants was delayed. Such eventualities may be avoidable if low volume, higher value-added products can also be made at the same site.

Box 1. Cascading use of biomass

Using biomass as a production material first and recovering the energy content from the resulting waste can provide multiple benefits. Biomass use may be further improved by recycling it several times before a final energetic utilisation at the end of its lifecycle. Such cascading systems may provide general advantages for climate change mitigation and land use (UNEP, 2009).

An on-going increase of production of biomaterials may reach between 10-11% of the overall land requirements for the consumption of agricultural goods in Germany by 2030. Therefore, although biomaterials are often superior to biofuels with regard to environmental performance as substitutes for fossil-based products, increased demand may result in similar pressure on land use as biofuels.

Although cascading tends to mitigate the competition between different types of biomass use, few comprehensive analyses of cascading systems have been made. Therefore, the concept should be the subject of research to ascertain its value.

In the Brazilian sugar cane industry, for example, large amounts of lignocellulosic materials, especially bagasse, are readily available, typically produced as by-products of sugar and ethanol production. Most of the bagasse produced in the mills, where sugar cane juice is separated from the fibre, is used as fuel in co-generation systems to supply the energy demand of the bioethanol production process. The use of sugar cane lignocellulosic fractions as fuels in electricity production for sale to the grid is commercially and technically feasible in Brazil (Cardona et al., 2010). If electricity prices are favourable, more material that is lignocellulosic may be diverted for production of steam and electricity, and *vice versa* when ethanol prices are more attractive (Dias et al., 2013).

Chemicals, plastics and the competition for crude oil

Plastics production is the largest sub-sector of the petrochemicals industry, and such is the success of plastics as materials that their market position is going to increase at a significant pace. Plastics have shown an almost exponential growth during the past decades and currently over 200 million tonnes per annum are produced worldwide. One source has predicted that overall demand for plastics could increase four- to five-fold by the end of this century (Lemstra, 2012). Similarly, the USDA (2008) has predicted that overall chemicals production could almost double by 2025 (compared to 2005).

Plastics are used extensively in the automotive sector, where continued growth is expected. Before the recent economic recession, more than 70 million motor vehicles were sold every year round the world – bringing the total number on the road to over 800 million recently. By 2030, this figure could reach 1.3 billion vehicles and by 2050, the total may be more than doubled again to three billion vehicles – mainly due to growth from emerging markets such as Brazil, Russia, India and China.[16]

In BP's *Energy Outlook 2030*[17] of 2012, it is expected that the efficiency of the internal combustion engine (ICE) will double over the next 20 years, largely driven by continued hybridisation of the car fleet. Nevertheless, that will probably mean at least a doubling of the plastics used in automotive production by 2030, and quadrupling the quantity by 2050, and probably more as new plastics applications are researched in order to reduce the weight of vehicles.

Table 3 gives a prediction from the US Department of Agriculture (USDA, 2008) for the growth of the chemicals and bio-based industries to 2025. The USDA study projects that the global chemical industry will grow 3–6% per annum through to 2025, by which time the total production of chemicals would have risen over 80% from the 2005 figure.

Table 3. US predictions for growth of the chemicals and bio-based materials industries to 2025 (in USD billions)

	2005		2010		2025	
Sector	**Total**	**Bio-based**	**Total**	**Bio-based**	**Total**	**Bio-based**
Commodity	475	0.9	550	5-11	857	50-86
Specialty	375	5	435	87-110	679	300-340
Fine	100	15	125	25-32	195	88-98
Polymer	250	0.3	290	15-30	452	45-90
Total	1,200	21.2	1,400	132-183	2,183	483-614

Source: USDA (2008)

The demand for crude oil also needs to be examined. Overall, demand for oil is expected to continue to grow at less than 1.0% annually.[12] Although this sounds modest, it adds up to an additional 16 million barrels per day by 2030. That is roughly 1.5 Saudi Arabia equivalents. There is likely to be plenty of oil still to be discovered, but all evidence suggests that it will be increasingly expensive, and maintaining such growth in the long term will be extremely challenging.

Growing demand for plastics and chemicals creates an obvious dilemma for the petrochemicals industry. The feedstock for producing synthetic plastics is almost exclusively crude oil and currently around 5% of oil production is used for making plastics. By the end of this century, 20-25% of current crude oil production will be required for plastics production alone. To this has to be added the increasing

demand for chemicals production, meaning that the demand for crude oil from chemicals and plastics alone in relation to total production may become unsustainable.

Therefore, apart from the grand challenges being faced by society, a fundamental issue that cannot be ignored is that competition for crude oil is getting more severe, and the trend in prices seems set to be upward.

Climate change and greenhouse gas emissions

In some countries, the primary motivation for the recent upsurge in the development of bio-based products is reduction of GHG generation, with correspondingly lower impacts 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. In May 2013, for the first time in recorded history, daily CO_2 readings at a US government agency lab on Hawaii topped 400 parts per million.[18] Several countries have adopted targets for 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. To date, 167 countries have signed up to the Copenhagen Accord,[19] trying to limit the temperature rise, compared to pre-industrial levels, to 2ºC.

Weiss et al. (2012) compared cradle-to-grave GHG emissions associated with conventional and bio-based chemicals, based on 44 LCA studies covering approximately 60 individual bio-based materials and 350 different life cycle scenarios. They found that the bio-based materials save, on average, 55 +/- 34 MJ non-renewable energy and 3 +/- 1 kg CO_2 per kg material compared to their fossil-based counterparts.

However, the Weiss paper highlighted a large variability in the estimates of bio-based product GHG savings, resulting from differences in the background assumptions, system boundaries and methodologies used in the LCA calculations. All vary across different studies, and the results are not easy to compare. Also, most such studies deal with ethanol, polylactic acid (PLA) or polyhydroxyalkanoates (PHA). Another limitation is that bioprocess data are often limited.

Hermann et al. (2007) attempted to standardise cradle-to-grave methodology to compare the environmental impacts of various bio-based chemicals with their fossil-based equivalents (Table 4).

Table 4. Potential worldwide annual production and best-case GHG savings of nine bio-based chemicals, with corn starch feedstock and using cradle-to-grave analysis

	Annual GHG savings (kt CO_2/year)	
Product	**Today**	**Future**
Acetic acid	N/A	9570
Acrylic acid		4380
Adipic acid	N/A	7880
Butanol	3040	9610
Caprolactam		20 100
Ethyl lactate	1580	2220
Ethylene	191 050	245 710
Lysine	1370	2280
Succinic acid	6070	6780

Note: The analysis did not account for future chemical industry changes.
Source: Hermann et al. (2007)

They showed that the potential GHG savings for the production of bio-based products using current technology and corn starch as a feedstock was already 45% compared to the savings involved in the production of fossil-based equivalents. The future saving potential is even higher if lignocellulosics or sugar cane are used as feedstocks.

Substantial further savings are possible in the future through improved fermentation and downstream processing, and improvements due to consolidated bioprocessing and synthetic biology are expected in the longer term. They concluded that worldwide CO_2 savings in the range of 500-1 000 million tons per year are possible using future technology.

Sophisticated predictive modelling with a horizon of 2030 by a team in the Netherlands (Hoefnagels et al., 2013) indicates that the production of only three bio-based chemicals (ethylene, caprolactam and hydrogen) and second-generation biofuels can result in large reductions in CO_2 emissions (over 27% compared to 2006 values).

If such predictions become reality, then bio-based chemicals production offers excellent opportunities for mitigating GHG emissions and decreasing dependence on fossil energy sources. However, the variability in calculations is a serious impediment to bio-based production, and international standardisation is required for the credibility of the industry. Serious misgivings concerning the use of LCA as the sole tool in environment impact assessment have been raised (ANEC, 2012). The authors claim that, in some cases, European policy was based on flawed LCA results (e.g. biofuels). This subject merits further attention by policy makers.

Most remaining hydrocarbon reserves cannot be burned

Sophisticated models suggest that limiting cumulative CO_2 emissions over 2000–2050 to 1 000 Gigatons (Gt) of CO_2 yields a 25% probability of warming exceeding 2ºC (Meinshausen et al., 2009). A recent update estimates that the available budget is 1 075 Gt CO_2 for a 50% probability of staying below 2°C, confirming that most of the remaining fossil fuels are non-burnable (Carbon Tracker, 2013). In addition, achieving a 2°C scenario means only a small amount of fossil fuels can be burned after 2050.

The world is not on track to meet the 2°C target. Despite positive developments in some countries, global energy-related CO_2 emissions increased by 1.4% to reach 31.6 Gt in 2012, a historic high (IEA, 2013). The need for new forms of renewable energy and sustainable manufacturing has never been more urgent.

Food security and land use

The impact of bio-based production on food supply is very much a live debate. The international food price increases that were experienced in 2008 ignited controversy over biofuels production – the so-called food versus fuel debate (e.g. IFPRI, 2010; Mueller et al., 2011). Evidence links first-generation biofuels to the price spike, but the actual extent of the linkage will probably never be known (Abbott et al., 2008; de Gorter et al., 2013). Next-generation lignocellulosic ethanol production has, as a primary policy goal, the breakage of this link between land requirements for food and fuel.

Water security is obviously directly linked to food security. The scale of its importance is worth highlighting. As many as two billion people rely directly on aquifers for drinking water, and 40% of the food in the world is produced by irrigated agriculture that relies largely on groundwater. Vast territories of Asia rely on groundwater for 50-100% of the total drinking water (UNEP, 2003). Whilst bio-based production has great potential for GHG emissions savings (e.g. Weiss et al., 2012), the production of extra non-food biomass requires a great deal of water, thus potentially putting it in competition with other vital water uses. For example, one study (Gerbens-Leenes et al., 2009) found that, for biodiesel production,

soybean and rapeseed (crops mainly grown for food) had the best water footprint. Jatropha, often cited as a great future hope for biofuels production, had the least favourable.

The impacts of GHG emissions from land use changes (direct, DLUC, and indirect, ILUC, (Box 2) are considered to be critical factors in the sustainability of bio-based production. Many Members of the European Parliament (MEPs) have long been calling for ILUC to be factored into measuring the value of biofuels. However, ILUC measurement is extremely challenging. The analysis by Searchinger et al. (2008) highlighted the significance of land-use change contributions towards agricultural emissions of GHG. Although the approach involved a high level of uncertainty, the consequences of GHG emissions from direct and indirect land use changes cannot be ignored.

Box 2. Direct and indirect land use change.

(Direct) land use change (DLUC)

In general, the conversion of land (e.g. pasture land, forests, wetland or degraded land) into agricultural land for bioenergy production is known as (direct) land use change (LUC) as its utilisation and land coverage changes (UNEP, 2009).

(Indirect) land use change (ILUC)

The hypothesis concerning indirect land use change (ILUC) states that GHG emissions from land use change can occur when farmers respond to higher prices and convert forest and grasslands to new croplands to replace cropland diverted to biofuels. ILUC effects are considered by some to be impossible to assess as they occur beyond the limits of the biomass production chain.

Key data and modelling challenges, such as calculating the impact of land conversion on carbon stocks, data set variations on land use characteristics and complex interaction of socio-economic forces, all guarantee large uncertainty in results (US DoE, 2011). To assess accurate levels of emissions from these sources, it is important to develop strategies that provide improved and deeper understanding of the interaction between land use changes and GHG emissions.

Dealing with ILUC and its uncertainties in policy

It is generally accepted that not all biofuels are equal and, therefore, it is important that policies encourage uptake of the 'right' types of biofuels that are both sustainable and deliver the required GHG savings. Two other very general points can be considered when dealing with ILUC in biofuels policy:

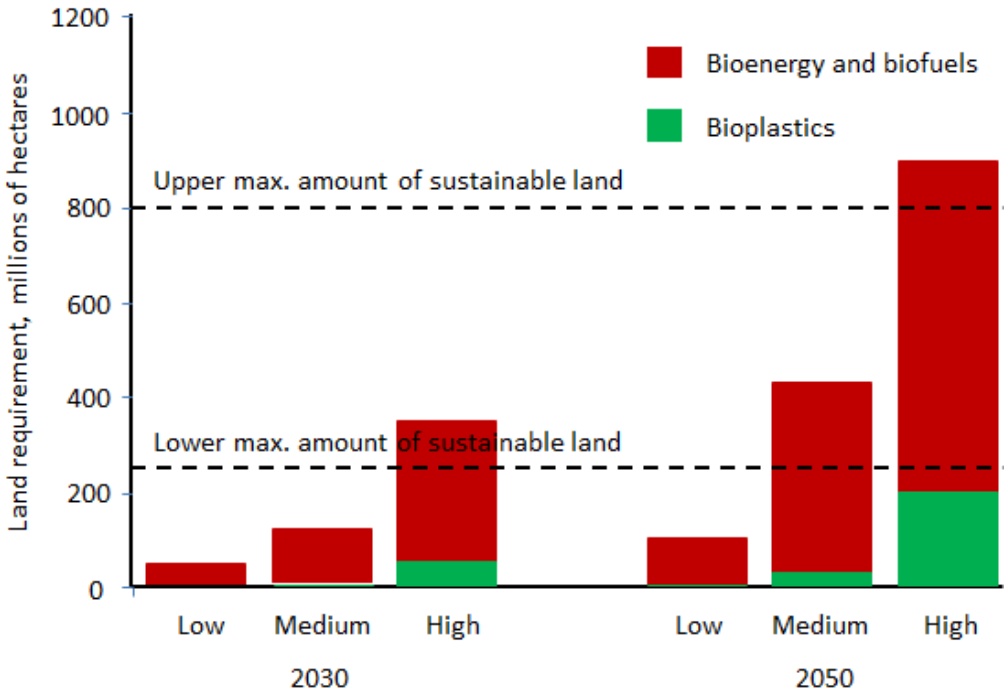
1. Policy stability is critical for investor confidence; uncertainty created over ILUC policy direction could significantly restrain investments needed to meet climate change and renewable energy targets;
2. Some of the potential solutions being proposed to monitor or regulate ILUC could create inconsistencies with related policies.

Rather than several suggested command-and-control measures, a market mechanism through the use of a carbon credit scheme may be a better approach to mitigate ILUC (Ernst & Young, 2011). That is, by assigning a carbon credit to biofuels that prevent or reduce the risk of ILUC, it may be possible to create financial value to incentivise the adoption of practices that prevent or mitigate ILUC.

Due to the much smaller production volumes (and in some cases higher land area efficiency) compared to fuels, bio-based materials production has far smaller consequences for land use, and therefore the potential impacts on food supply are concomitantly lower (see, for example, Endres and Siebert-Raths,

2011). If compared on a hectare basis and without residue utilisation, most bio-based polymers score better in terms of energy savings and GHG emission reduction than bioenergy production from energy crops (Dornburg et al., 2004). An analysis by Higson (2012) (Figure 4) predicts much lower land requirements for bioplastics than bioenergy and biofuels, both at 2030 and 2050. In quantitative terms, however, much work remains to be done. Nevertheless, it seems evident that the industrial material use of biomass makes fewer demands on resources and reduces pressure on land and biomass compared to energy and fuel uses (Carus and Dammer, 2013). Box 3 shows an analysis specific to the replacement of single use plastic carrier bags.

Figure 4. Predicted biomass demand scenarios versus land availability in 2030 and 2050



Source: Higson (2012)

Box 3. Replacing the whole European market for single-use carrier bags

The European market for single-use carrier bags is estimated to be 100 billion bags per annum. This corresponds to about 1.2 million tonnes of plastics, assuming a weight of 12 g per bag. To totally replace this with biodegradable bags derived from corn starch would require the following (Ganapini, 2013):

- 1.2 million tonnes of starch as dry matter, extracted from 1.82 million tonnes of grain (dry matter) with a starch content of 66%;
- 280 000 hectares of land to grow this amount of corn in Europe with an average yield of 6.6 tonnes of grain per hectare.

In the European Union, there are at least 2.5 million hectares of arable land currently not in use (Carus and Dammer, 2013). The authors estimate that the land requirement for bioplastics globally is one to two orders of magnitude lower than the global requirement for land for biofuels. Therefore, it could be argued that the effects on food prices of bioplastics production could be 10-100 fold less than biofuels.

Rural regeneration and job creation

Modern agriculture is a highly efficient enterprise in many OECD countries, with strong productivity growth being recorded in developed countries, especially from the 1960s through the 1990s (OECD, 2011c), but these efficiencies have led to job losses. For the United States, a major driving force for industrial biotechnology is the regeneration of the rural environment, where a huge number of agricultural jobs have been lost due to increased efficiency (USDA, 2010). Over the last 60 years, the percentage of the US population directly involved in production agriculture has gone from 15% to less than 2%, but the average farmer produces food for 155 people today, as compared to his counterpart 60 years ago, who produced food for only 25 people.

In Europe, there is also a desire to keep chemical industry jobs, as the chemicals sector has been vital to the European economy. Data for the 10 years from 1999 to 2009 indicate that the European Union has been the clear leader in terms of world chemical sales, but the region has gradually lost ground to Asia, principally due to the rise of China (Hadhri, 2010).

The development of biorefineries using agricultural and forestry materials as the feedstock for bio-based production has become a topic on the agenda of the European Union. The main limitation on the use of raw materials from agriculture is related to their typical low economic value and energy density. Long distance transportation is a limiting factor in economic terms (Mayfield et al., 2007). There are thus valid reasons for locating biorefineries in rural environments, since this allows them to be as close as possible to the main agricultural or forestry areas.

However, the promotion of a new industry in rural areas is typically hindered by scarcity of human capital, lack of information, poorly developed infrastructures, and the existence of competing development options, all of which have strengths and drawbacks that have to be considered by public decision makers (Lopolito et al., 2011).

Second generation cellulosic biorefining provides the greatest potential for rural development. A recent study (Bailey et al., 2011) has shown a high potential for economic development and job growth through lignocellulosic biorefining, especially in the logging sector and in rural regions of Alabama, which is a state that combines both abundant timber resources and persistent rural poverty.

Whilst environmental aspirations for the bio-based industries are important, job creation possibilities are likely to be at least as important a priority for policy makers (Peters et al., 2011). Both chemicals and plastics industry jobs in the United States went into steep decline from the 1980s, as oil rich countries began to invest aggressively in their own petrochemical industries (Biotechnology Industry Organization, 2010), and thus the jobs moved nearer to the feedstock. For every job created in the business of chemistry in the United States, 7.6 related jobs are created in other sectors[20] and on average they are highly paid compared to other manufacturing jobs. The employment opportunities also seem excellent compared to fossil industry employment. Compared to fossil fuels in Europe, biofuels create 50-100 times the number of jobs; electricity from biomass creates 10-20 times the number of jobs; and heat from biomass creates double the number of jobs (European Commission, 2005).

The Blue Green Alliance estimated that shifting 20% of current plastics production into bioplastics would create a net 104 000 jobs in the United States economy (Heintz & Pollin, 2011). Federal policy in the US supporting biofuels resulted in an additional 240 000 jobs and contributed USD 65 billion to GDP in 2008 (Carr et al., 2010). If current growth in bio-based chemicals can be maintained in the United States, it would create or save tens of thousands of additional jobs, even in the near-term (*Industrial Biotechnology*, 2011, Industry Report).

Meanwhile, modelling in Europe indicates that bio-based chemicals and plastics production can support more jobs per tonne of biomass than biofuels and bioenergy applications. Carus et al. (2011) have estimated that materials use can directly support 5–10 times more employment and 4–9 times the value-added compared with energy uses, principally due to longer, more complex supply chains for material use.

Flanders recently published a bioeconomy report (summary in English edited by Van Melkebeke, 2013) that confirmed that, in Flanders, bio-based products (such as paper, wood-fibre boards, bioplastics and biochemicals) have created 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). A publication of the JTI- BI public-private partnership, under development in Europe, shows similar job numbers in Europe for biofuels and bio-based chemicals and plastics, of the order of 150 000 in each sub-sector, whereas bio-based chemicals and plastics generated a turnover of EUR 50 billion compared to EUR 6 billion for biofuels (BRIDGE 2020, 2012).

Modelling to 2030 by Hoefnagels et al. (2013), using a variety of scenarios, indicates that 3-5% of agricultural employment will be related to the production of biomass for bioenergy or bio-based chemicals. In all scenarios, the added value is predicted to increase in all sub-sectors of bio-based production, i.e. electricity, transport fuels and chemicals. However, the share of income in these sub-sectors is predicted to be greatest due to the quantities of bio-based chemicals production, this modelling being done for only three bio-based chemicals. In their economic analysis, this bio-based substitution requires hardly any subsidy if competing with high fuel prices. They also predict positive trade balance effects for the Netherlands.

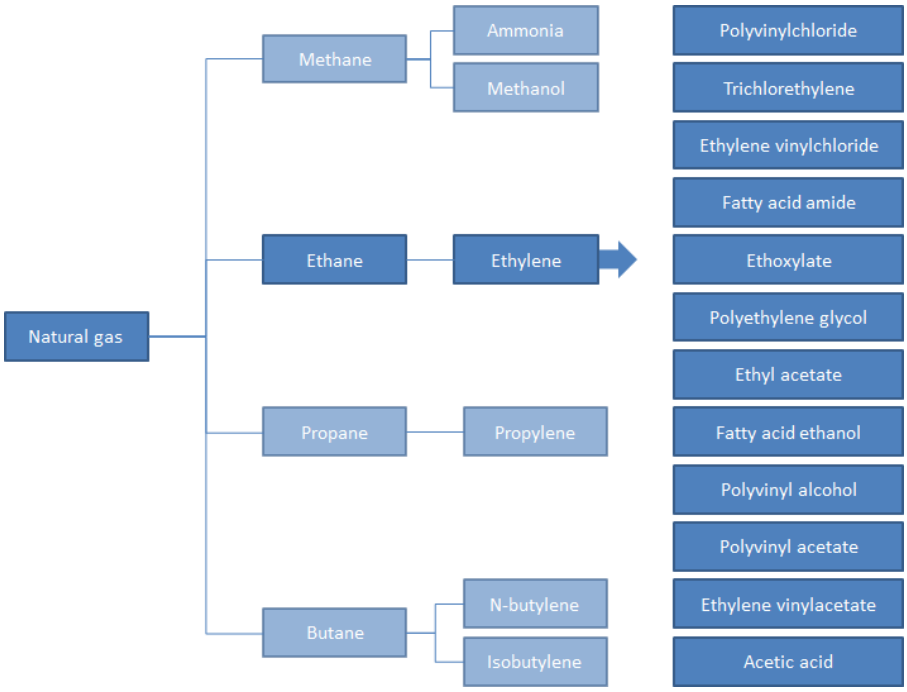
The shale gas effect

Ostensibly, the availability of cheap natural gas via the United States shale gas boom (see US Energy Information Administration, 2013), or the mining of deep ocean gas hydrates (see *New Scientist*, 2013), has a greater potential to affect the energy and electricity generation markets than it has to affect the chemicals and plastics markets. Seventy-five percent of shale gas, for example, is low value methane that is primarily used in energy production. The availability of cheap natural gas, however, could also have beneficial impacts on bio-based chemicals production.

The most valuable component of shale gas is ethane (typically about 16% by composition). The ethane chain (see Figure 5) is exceptionally important in the chemical industry as it leads to the production of ethylene, from which a large number of chemicals and plastics are derived (American Chemical Council, 2011). The shale gas boom in the United States and the low prices of natural gas have spurred a wave of investment in gas feedstock crackers that could lead to a 29% increase in ethylene capacity by 2017 (Chang, 2012), which in turn has led to the closure of naptha crackers in Europe and perhaps elsewhere. Some Japanese companies, for example, plan to close capacity in naptha and steam crackers.[21]

One consequence of this shift to gas feedstock crackers is that it is likely to drive up the prices of aromatics and C4 chemicals such as butanediol and butadiene, which can be produced via the use of naptha crackers but cannot be produced via gas feedstock crackers. This presents an opportunity for bio-based alternatives, which to date have found it difficult to compete on price with some of the products of naptha-crackers.

Figure 5. The gas to ethane chain



Source: PwC (2012)

Bio-based production and shale gas: threats and opportunities

At present, shale gas production has positive as well as negative implications for the bio-based production industry. The availability of inexpensive gas has potentially positive follow-on effects for bio-based production, especially regarding thermochemical processing of biomass. Biomass is about 50% oxygen by weight and the remainder is carbon and hydrogen. The oxygen in biomass needs to be removed and one of the most economical ways to do this is to react the oxygen in biomass with hydrogen (in shale gas), which allows the oxygen in biomass to be removed as water, leaving the carbon and hydrogen.

Therefore, the economic feasibility of using cellulosic or woody biomass to make advanced biofuels from inexpensive shale gas may become a reality. A number of advanced biofuel projects in the United States employ natural gas either directly or indirectly as a hydrogen source. These projects may benefit from the long-term fall in natural gas prices resulting from increased shale gas production.

Another view[22] is that the share of bio-based materials in the market is likely to remain relatively small until oil prices rise further. The biggest threat is to bio-based ethylene and propylene production, simply on price. However, when shale gas production increases sufficiently to permanently displace naphtha as the feedstock of choice in ethylene crackers, there will be a shortage of key petrochemicals, which will drive up their prices. Propylene prices could rise dramatically as a result of limited co-production of olefins in gas-fed ethylene crackers.

Which bio-based chemicals succeed on a large scale will depend more on technology advances, availability of funding and market pull than on developments in shale gas. Salmenkivi and Jääskeläinen (2013) believe shale gas will have positive effects on selected bio-based commodity chemicals and negative impacts on others (Table 5), with the positives outweighing the negatives.

Table 5. Predicted impacts of shale gas on bio-based chemicals

Shale gas impact on bio-based chemicals	
Positive	**Negative**
n-Butanol	Ethylene
Isobutanol	Propylene
Paraxylene	Monoethylene glycol
Adipic acid	
Butadiene	
Isoprene	
2,5-Furandicarboxylic acid	
Farnesene	

Source: Salmenkivi and Jääskeläinen (2013).

Conclusions

Liquid biofuels can fulfil some of the demand for road traffic fuels although the proportion is unclear and likely to be highly variable across different countries depending on local politics, land availability and ability to trade in biomass. Given some of the advantages that bio-based chemicals and plastics offer, the current focus of policy globally on biofuels alone seems at odds with plans for a future bioeconomy.

BIO-BASED CHEMICALS POLICY: WHAT THERE IS AND WHAT MIGHT WORK

"*In addition to fuels, the bioindustrial space comprises a broad range of products, especially high-value specialty materials. There is a torrent of activity in the space: project announcements, industry partnerships and joint ventures, policy developments, and financing activity*".

Source: Raymond James Equity Research, April 23, 2014

One of the major messages from this section is that the policy regimes supporting biofuels in many countries and regions do not also support bio-based materials (chemicals or plastics). This is the case, for example, in the United States (Industrial Biotechnology Industry Report, 2010) and the European Union (Carus *et al.*, 2011). Yet some bio-based products are much closer to market, at scale, than are second-generation biofuels (Shaw *et al.*, 2011), and several authors have shown that bio-based materials offer higher GHG savings than bioenergy per kg biomass used or per hectare (e.g. Anex and Ogletree, 2006; Vinke et al., 2007).

Some venture capitalists are now of the opinion that basic chemicals and simple polymers represent the "sweet spot" for funding (Hasler, 2010), on the basis that more people are convinced that fuel production alone from cellulosic biomass is not the most viable business strategy. Greater dialogue between the investor community and the public sector is needed to stimulate this investment – perhaps via public-private partnerships – and to evolve appropriate bioeconomy strategies.

As part of this current project, a survey is being conducted among OECD Member States, and some others strategic to the bio-based production industry, to gather information on what policies are being used specifically to support bio-based chemicals production. Table 6 illustrates the different policy support measures for bioenergy, biofuels and bio-based chemicals in the European Union.

Table 6. Main European Union policy instruments on biomass use (excluding food and feeds)

Instrument	Biofuels	Biogas or bioelectricity	Wood pellets for electricity	Bio-based products (non-fuel)
Tax reduction	Yes	(Yes)	Yes	No
Quota (Biofuel, Renewable Directive)	Yes	Yes	Yes	No
Green feed-in tariff for electricity	Yes	Yes	Yes	N/A
Emissions Trading System (ETS)	Yes	Yes	Yes	No
Market introduction programmes	Yes	Yes	Yes	A few
Other (e.g. rural development schemes)	Yes	Yes	Yes	No
Research and development	Yes	Yes	Yes	Yes

Source: Carus (2013)

The private sector is not incentivised to invest in biochemical production compared to the situation with bioenergy and biofuels, an issue of concern in the balanced development of a bioeconomy and the operation of integrated biorefineries. In short, the formidable financial barriers include: very long innovation cycles for new products; competition from a highly evolved and efficient global petrochemicals industry; and daunting capital requirements to bridge the gap between laboratory-level proof-of-concept and commercial production.

Two separate policy issues are described in this section:

1. What are the policies that would help bring about greater investment in bio-based materials and help to redress the balance with bioenergy, but especially with liquid biofuels;

2. What other policy gaps need filling in order to "join up" the policy mix.

Policies to redress the balance with bioenergy and biofuels

There is a danger for any nation that bioenergy and biofuels policies involving subsidies will drive a competition for land and biomass that makes it difficult for bio-based chemicals and plastics (i.e. materials) industries to flourish. Many policies supporting the use of bioenergy reward the use of biomass for energy purposes. As energy and materials compete for the same biomass or agricultural land, this puts bio-based materials at a disadvantage (Hermann et al., 2011). In the European Union, the Renewable Energy Directive (RED), which has ambitious targets for bioenergy and biofuels development, systematically allocates biomass to energy to the disadvantage of materials.

The RED triggered national action plans to build support for bioenergy and biofuels. This in turn has driven up biomass prices and agricultural leases. This makes it difficult for other sectors to acquire biomass. Unlike oil and gas, the ownership of biomass is highly fragmented. In Europe alone there are some sixteen million forest owners (BRIDGE 2020, 2012). Many contracts are based on long-term fixed prices, which locks in both supplier and customer so that neither can take advantage of biomass price fluctuations. Increasing demand is likely to drive up the price of biomass significantly (Deloitte, 2012) in a market constrained by supply, not demand.

Such price rises have already started (e.g. pellet prices in Germany have increased substantially in the past year, from an average of EUR 227 per tonne in the second quarter of 2012 to EUR 267 per tonne in the second quarter of 2013,[23] a rise of over 17%). In the context of bio-based production of chemicals and plastics, this represents two threats to biomass supply, first of all based on availability in competition with bioenergy, and secondly on price. Bioenergy applications will continue to take advantage of fixed prices, whereas biomaterials applications, not eligible under these contracts, will have to pay increasing prices.

One policy option is to allow materials to take advantage of the existing regimes for bioenergy and biofuels. The synergies are more likely to be seen with biofuels, as this is truly an industrial biotechnology, whereas bioenergy currently involves little biotechnology (although this will change in the longer term if synthetic biology can be applied to biomass sources). Table 6 acts as a reference.

Feed-in tariffs

Feed-in tariffs (FITs) as applied to bioenergy are not relevant to bio-based chemicals and plastics. FITs require that an equivalent of a national grid exits. Under a FIT, eligible renewable electricity generators, including homeowners, business owners, farmers and private investors, are paid a cost-based price for the renewable electricity they supply to the grid. Whilst well-adapted FIT regimes can be the most efficient and effective support schemes for promoting renewable electricity, application to highly diverse chemicals and plastics is impracticable.

Quotas and mandates

At first sight, quotas/mandated production levels may also seem impracticable. These can work when applied to fuels, as the diversity of fuel types is very low (essentially petrol, diesel, and aviation fuel, with other more minor types). They can therefore be set up and administered at the national level with relative ease. However, given that there are potentially hundreds of chemicals and plastics, the administration of quotas seems inordinately complex and expensive. It would also be strongly resisted by industry.

A solution that may work has been suggested by Carus et al. (2013). This involves opening the provisions of the RED to bio-based materials. By doing so, they envisage a recasting of the RED as the *Renewable Energy and Material Directive* (REMD). Their suggested mechanism that would avoid creating and administering individual quotas for hundreds of different chemicals is to use bioethanol as a reference chemical. Ethanol made using certified sustainable biomass, then used for the manufacture of chemicals and plastics, could be counted in the same way that ethanol is counted for a biofuel (i.e. single counting for first, double counting for second, and quadruple counting for third generation biofuels). All other bio-based chemicals that are not derived from ethanol, such as lactic and succinic acids, could be converted to ethanol "equivalents", on the basis of their calorie value in comparison to ethanol. Knowing the global production volume of the chemical would then allow the setting of a production quota for that bio-based chemical.

The initial goal of the RED was the reduction of GHG emissions, so therefore it may seem more intuitive to base the above quota system on avoided GHG emissions than calorie value. However, basing the calculation on calorie value would present fewer legal difficulties. Given the lack of support in many countries for a carbon tax, the legal quandary is thus avoided.

Such a quota system would offer the bio-based materials industry a similar level of security to the one enjoyed by bioenergy and biofuels. It would also give countries another option when fulfilling their target RED quotas. A recent report (European Commission, 2013) has shown that most European Union member states are having difficulty meeting their renewable energy quotas. Adding a bio-based chemicals and plastics option would allow countries to meet their RED quotas, whilst also creating the necessary conditions to stimulate their chemicals and plastics industries. It can be envisaged that such a mechanism would therefore boost private investment in bio-based materials production.

Given the much lower production volumes of chemicals and plastics compared to fuels, this should be a cost-effective means for governments to stimulate the bio-based materials sector. Lapan and Moschino (2012) found biofuels production mandates to be more revenue-neutral than tax and excise reductions. They derived that an ethanol volume mandate is equivalent to a combination of an ethanol production subsidy and a fossil fuel (petrol) tax that is revenue-neutral. They conclude that the (optimal) ethanol mandate yields higher welfare than the (optimal) ethanol subsidy.

There are also some lessons to be learned from weaknesses in biofuels quotas and mandates. A limiting factor of this option is the fact that, in most cases, mandates do not distinguish among biofuels according to their feedstock or production methods, despite wide differences in environmental costs and benefits. This implies that governments could end up supporting a fuel that is more expensive and has a higher negative environmental impact than the corresponding petroleum product (Global Subsidies Initiative, 2007). A key to preventing such a mistake in bio-based materials production support in the short term involves harmonising life cycle analysis within the industry. In the longer term, it involves developing a robust and internationally coherent sustainability assessment regime.

Tax incentives

"*Uruguay has recently approved strong tax incentives for biotech companies. This new law is a milestone in the implementation of the national strategic plan for Uruguay's fast growing biotech industry that has been officially declared strategic for the country's future industrial development. In addition to tax incentives, the plan also promotes the creation of human capital, the development of an industry cluster in Montevideo, the simplification of product registration processes and incentives for seed and venture capital investments.*

Under the new law, biotech start-ups as well as existing business that will contribute towards the development of specific value chains can benefit from tax breaks of 50% to 90% of corporate tax until 2021.

The biotech sub-sectors specifically targeted by these benefits are agro, renewable energy, environment and human and animal health. These benefits are not only available to companies manufacturing biotechnological products but also for those providing biotech services as well."

Source: Uruguay implements tax incentives for Biotech industry until 2021, *Il Bioeconomista,* October 01, 2013

Whilst very common and effective, tax incentives are easier to apply in some places than in others. Difficulties applying a common tax incentive scheme for the bio-based materials industry would be encountered in Europe, as taxation is an individual country responsibility. In the United States, however, tax incentives are regarded as an important way to stimulate the bio-based materials industry.

Measures designed to open up biofuels policy instruments to bio-based materials have been discussed in both the US and the EU. In the US, a range of such measures was suggested during the US 112th Congress, with some measures reintroduced subsequently in the 113th Congress. In summary, these are as follows:

- H.R.4953 / S.3491, Qualifying Renewable Chemical Production Tax Credit Act *of 2012* (www.govtrack.us/congress/bills/112/s3491/text)

  This is classed as a Production Tax Credit (PTC). It promotes investment and domestic production for innovative renewable chemicals. The Qualifying Renewable Chemical Production Tax Credit Act of 2013 was reintroduced in both chambers.

- S. 1764 (112th): Make It in America Tax Credit Act *of 2011* (www.govtrack.us/congress/bills/112/s1764/text)

  This is classed as an Investment Tax Credit (ITC). It sanctions the eligibility of renewable chemicals and bio-based products manufacturing under the Advanced Energy Project Credit scheme (IRC Section 48C) and offers a 30% tax cut for new, expanded or re-equipped manufacturing.

- H.R. 6559 / S.3595, High Technology Small Business Research Incentives Act *of 2012* (www.govtrack.us/congress/bills/112/hr6559/text)

  This is classed as a R&D Tax Credit. It provides support for new and emerging R&D-performing renewable chemical companies to enter into joint ventures with investors.

- S. 3240 Agriculture Reform, Food, and Jobs Act *of 2012* (www.govtrack.us/congress/bills/112/s3240/text)

This provides a definition of "renewable chemical" as "a monomer, polymer, plastic, formulated product, or chemical substance produced from renewable biomass."

- Master Limited Partnerships Parity Act (ML), S.795 (www.govtrack.us/congress/bills/113/s795/text)

  This contains renewable chemicals language for the first time, gives access to low-cost capital enjoyed by fossil fuel energy sources, attracts investors and replaces two corporate stock taxes with a single tax.

- S. 2155 (112th): A bill to amend the Farm Security and Rural Investment Act of 2002 to promote bio-based manufacturing (www.govtrack.us/congress/bills/112/s2155)

  This promotes renewable chemicals and bio-based products in domestic manufacturing.

  In addition, the House and Senate Agriculture Committees approved five-year farm bills containing an energy title – *Senate version, S.954* – which calls for some USD 800 million in mandatory funding for farm energy programmes and contains renewable chemical language.

The existence of a production tax credit (PTC) in the US covering bio-based products could promote investment, production, and adoption of bio-based products, much as existing biodiesel and cellulosic biofuels production tax credits have done for investment in those industries. Regarding the 48C advance energy credit, there has been a call for clarification on the eligibility of the manufacture of bio-based chemicals. The current 48C advanced energy manufacturing credit provides assistance to developers of a wide range of renewable energy technologies, including biofuels projects, but fails to recognise bio-based manufacturing projects as explicitly eligible.

A recent written statement (BIO, 2013) from the US Biotechnology Industry Organization (BIO) to the US House Committee on Ways and Means Working Group on Energy Tax Issues summarised these possibilities. The greater focus of this document was on the expiry of advanced biofuels incentives, but it described these tax provisions as "*essential ingredients in any effort to accelerate the commercialisation of advanced biofuels, renewable chemicals and bio-based products*." BIO requested the inclusion of these provisions in any energy or manufacturing tax package.

Tax based on carbon content

Considering biofuels, taxes on carbon content of fuels, accompanied by certification, may be efficient measures because taxes target CO_2 emissions directly (OECD/ International Transport Forum, 2007). However, opposition to carbon tax has been significant in many countries and, thus far, only 9 OECD countries have introduced carbon taxes after Sweden did so in 1991. The objections often centre on concerns that firms might relocate and that jobs may be lost. OECD work in this area indicates that carbon taxes are more efficient than direct regulation. Nevertheless, many large users of carbon resources in electricity generation are resisting carbon taxation. For bio-based chemicals and plastics, the environmental and financial considerations are much lower, but politically the same difficulties are likely to be met.

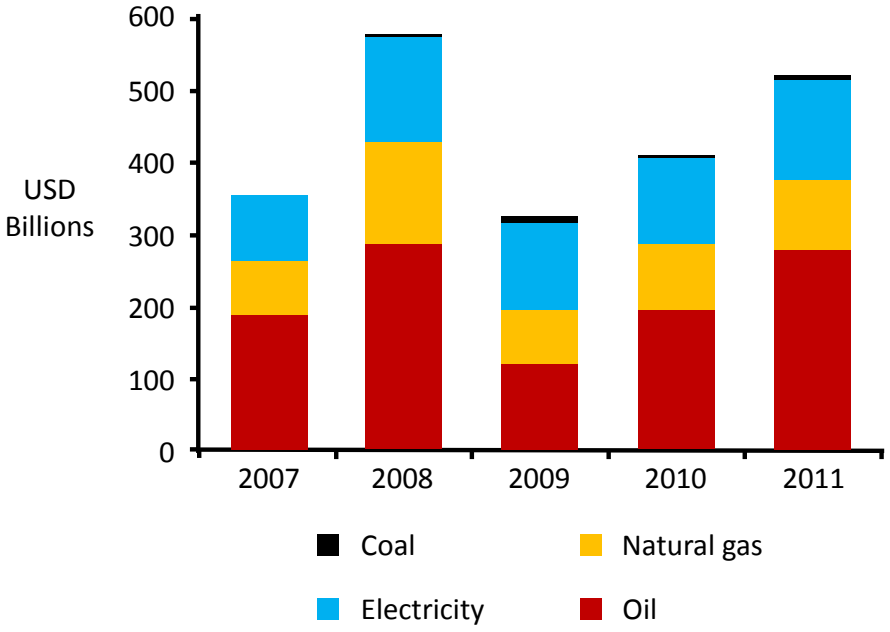
Many bio-based products are either carbon-negative on a lifecycle basis, or are superior in GHG emissions compared to fossil equivalents, because they sequester atmospheric carbon within the product itself. In the United States, however, because the carbon embodied in plastics and other chemicals rightly falls outside the cap envisioned by current climate legislation proposals in Congress, these bills do not adequately distinguish between bio-based and fossil-based products, and thus provide little incentive for development or production of bio-based products that displace fossil-fuel based alternatives. A possibility for Congress might therefore be to include 'production of bio-based products' in the list of eligible offset project types. Doing so might provide the necessary market signal to drive investment in critical low-

carbon bio-based products while providing obligated parties access to real, verifiable and additional CO_2 reduction opportunities.

Action on fossil fuel consumption subsidies

The global fossil fuels market is distorted by the existence of large fossil fuel consumption subsidies in some, mostly non-OECD, countries. Year-on-year this amounts to hundreds of millions of US dollars (Figure 6). These subsidies rose dramatically in 2011, almost entirely due to the increase in international energy prices, particularly oil prices.

Figure 6. Economic value of fossil fuel consumption subsidies (by fuel)[24]



Source: IEA (2012)

There are several good reasons for phasing out fossil fuel consumption subsidies. They can result in an economically inefficient allocation of resources and market distortions. By protecting parts of the market, they can also make the rest of the market more volatile. Moreover, the prospect of higher international prices means that fossil fuel subsidies could represent a growing burden on state budgets. For net exporting countries, subsidies could act to restrict export availability by continuing to inflate domestic demand, leading to lower export earnings in the longer term.

In 2011, fossil fuel consumption subsidies worldwide are estimated to have totalled USD 523 billion. To put this in perspective, global financial support to renewable energy amounted to only USD 88 billion in 2011 (IEA, 2012). For Germany, all of *Energiewende*, the policy to transform German energy production towards a much greater reliance on renewables, is likely to exceed EUR 1 trillion (Schiermeier, 2013). The International Monetary Fund (IMF) published a report in 2013[25] showing that almost 9% of all annual country budgets are spent supporting oil, natural gas and coal industries through direct subsidies, consumer rebates and avoided taxes on pollution. The report estimated that worldwide subsidies to fossil

fuels total a staggering USD 1.9 trillion – equivalent to 2.7% of global GDP, or 8% of government revenues.

Some developing countries have committed to subsidy reform, in most cases because high energy prices have made subsidies an unsustainable fiscal burden on government budgets. Phasing out such subsidies could make more finance available to those governments to invest in their climate obligations and energy security.

As for OECD countries, over 550 individual producer or consumer support mechanisms for fossil fuels have been identified in the present inventory throughout all 34 OECD economies (OECD, 2012). The aggregated value of these individual budgetary measures and tax expenditures amounted to between USD 55 billion and USD 90 billion annually during 2005-2011, although some caution is required in interpreting the support amounts. Nevertheless, it is clear that there is ample scope for both saving scarce budgetary resources and improving the environment through fossil fuel subsidy reform, not only in developing and emerging-market economies, but also in advanced countries. Diverting such savings towards support of bio-based production would be one way to achieve this without further burden on fiscal budgets.

Regulatory regimes

Fossil-based chemicals have several market advantages over bio-based equivalents. The former have had decades of development to perfect production processes and economies of scale have driven highly competitive pricing. Meanwhile, the pace of development of bio-based chemicals has outstripped developments in governance and regulation. It is important that bio-based and fossil-based chemicals are treated equally in regulatory policy - neither being inherently more benign nor more sustainable - so that neither is relatively disadvantaged. They are, after all, both chemicals.

In the United States, for example, the critical regulation is the Toxic Substances Control Act (TSCA). TSCA is a risk–benefit statute; that is, the US Environmental Protection Agency (EPA) is required to balance the regulatory costs against the likely benefits of a chemical regulation. An inventory of chemicals was created for TSCA in the 1970s and, naturally, most of these were fossil-derived. As such, many of the bio-based chemicals entering the market are, and will be considered as, new chemicals subject to TSCA regulation. This can lead to extensive regulatory scrutiny at the point of commercial introduction when these new, presumptively greener chemicals are attempting to break into the market and compete with established fossil-derived chemicals that, as inventory-listed substances, are not subject to such rigorous review. A clearly written description of the US situation is given by Bergeson et al. (2012).

The situation in Europe seems somewhat different. REACH is the European Community regulation on chemicals and their safe use.[26] It deals with the registration, evaluation, authorisation, and restriction of chemical substances. REACH aims to improve the protection of human health and the environment, while at the same time enhancing innovation and competitiveness of the EU chemicals industry. It appears that, in this respect, REACH deals with bio-based and fossil-based chemicals equally. However, interviews with companies showed that most did not consider REACH an incentive to look at substituting fossil-based materials by bio-based (Hermann et al., 2011).

Apart from harmonisation of LCA procedures, when LCA is used for regulatory purposes it is important that future technology improvement is taken into account when considering the environmental impacts of bio-based chemicals (Hermann et al., 2007). As petrochemical technology is mature, and bio-based production is in its infancy, there is vast scope for improvements in the environmental performance of bio-based chemicals that should not be disregarded.

A study for the government of the Netherlands (Sira Consulting, 2011) identified around 80 regulatory barriers to the bio-based economy. These were assigned different categories:

- *Fundamental constraints*. These call for a political and policy approach (e.g. import duties, level playing field, certification, and financial feasibility);
- *Conflicting constraints*. These barriers cannot be removed, but governments can help the companies to meet the regulations (e.g. REACH regulations);
- *Structural constraints*. These require adjustment to regulations, but do not demand policy or political action;
- *Operational constraints*. Here the regulation itself is not the problem but its implementation by, for example, local authorities. Especially for SMEs, these leads to substantial barriers to investment in the bioeconomy.

Other policy gaps

Bio-based chemicals pose a major challenge for policy makers because of the need to address the complete value chain of intermediate products in a cradle-to-grave perspective (Hatti-Kaul et al., 2007). Such chains are generally much longer than the equivalent ones based on fossil feedstocks, and the complete dependence on biomass naturally links bio-based production into other policy areas, especially agricultural policy, which is notoriously complex.

A distinct possibility when building a new technology is that policies are adopted which stand in isolation from each other. The specifics of bio-based production and industrial biotechnology, especially the reliance on new, untried supply chains for sustainable biomass, require a more holistic approach, in which policies integrate with each other. This is a difficult undertaking because of the strong possibility of creating opposing effects. Creating a bio-based production support policy might readily bring about a conflict with food or agricultural policy. For governments, a cross-ministry foresight exercise and on-going monitoring of policy integration are essential steps in preventing this.

Naturally, as with any developing technology, there are many policy gaps. The major elements are highlighted here along with some policy examples and options. The results of an analysis in the Benelux region (Box 4) typify existing concerns.

Box 4. A Benelux region workshop on hurdles and policies

The Benelux region[27] has great potential for innovation and the deployment of industrial biotechnology but, as in any other country or region that is gearing up to bio-based production, many technical and non-technical hurdles must be overcome in order to reach this potential. A regional workshop of the BIO-TIC project,[28] held at the Green Chemistry Campus, Bergen op Zoom, the Netherlands on 27th June 2013, addressed policy issues for industrial biotechnology in the Benelux region.

The most significant hurdles for the industrial biotechnology industry in the region, according to the workshop, were related to feedstock supply and price. This is perhaps the major message to policy makers. It is one that is heard frequently from many countries. Other hurdles ranged from technical issues including:

- The prohibitive price of enzymes;
- Poor yields (of both biomass and conversion processes); and
- The need to scale up from batch to continuous processing modes;

More market-based issues identified were:

- A lack of investment to promote R&D;
- A need for more pilot and demonstration activities;
- The prohibitive costs associated with IP protection, especially for SME's; and
- Complicated regulations over the use of some materials, for example wastes, are also perceived to be a hurdle.

A wide range of mechanisms by which industrial biotechnology could be promoted in the Benelux region were suggested and discussed. These included:

- Introducing financial support for farmers;
- Decreasing tariffs for imported biomass; and
- Introducing tax exemptions for bio-based products.

A more radical suggestion was that bio-based production should be included within the *Renewable Energy Directive* (RED) alongside fuels. More widely, it was suggested that biomass yields should be improved, waste regulations should be simplified for use in bio-based products and the principle of cascading use of biomass (Box 1) should be more widely adopted.

Increasing the visibility of industrial biotechnology through the exchange of best practices, promoting cooperation, developing networks and demonstrating viable business opportunities were identified as key routes to help develop the industry in Benelux. Improving the visibility of industrial biotechnology will also help raise funds for R&D, pilot and demo activities, whilst new business models, where the return on investment can be 5 years or more, would help support the industry.

Building demonstrator plants

Demonstrator plants are larger than pilot plants but smaller than full-scale production plants. Many technical, supply chain and economic issues become apparent in demonstrator plants and can therefore be addressed at this stage. It is therefore a vital stage to prevent very expensive mistakes at the full-scale production phase. This option is also suitable for gaining experience from small-scale experiments aimed at attracting the interest of potential participants (e.g. investors, credit institutes, local public policy makers, suppliers of raw materials, final users), many of whom are not yet aware of the opportunities presented by the new business. Yet demonstrator plants are notoriously difficult to finance, a barrier that could be addressed through public-private partnerships (PPPs) or other public support mechanisms.

Very recently, news of an Indian waste biorefinery demonstrator was announced.

"Praj Industries – the Indian global process solutions company for bioethanol, alcohol and brewery, water and wastewater – has emerged as the first Company in South Asia to set up an integrated 2nd Generation (2G) Cellulosic ethanol plant… The 2G Cellulosic ethanol demo plant will operate on a different variety of biomass with a capacity of 100 dry tonnes of biomass per day, which includes agricultural wastes such as corn stover, cobs and bagasse. The demo plant will enable Praj to consolidate its 6 years of R&D efforts, starting with laboratory trials to pilot scale trials. The same plant will also enable Praj to develop various biochemicals and bioproducts".

Source: http://pn.newsblaze.com/release/2013080801310200001.pnw/topstory.html

For the bio-based industries, the greatest urgency for demonstrator plants is waste biorefineries that operate through lignocellulosic conversion. Despite the attractiveness of algal biorefineries, governments should be aware of some factors that might limit their utility. For example, although there are locations with sufficient year-round levels of sunlight, that are close to plenty of water, in the vicinity of carbon-intensive industries that can supply inexpensive CO_2, and with developed road and rail networks that can support distribution of the raw materials and end products, these locations are by no means commonplace (Klein-Marcuschamer et al., 2013). When considering algal biorefining, such considerations could be major deciding factors for countries.

Capacity building and scale-up

At the commercialisation phase (i.e. beyond demonstration), there is a sense that a growing number of technologies conceived in the United States are being scaled up in Brazil, China, Thailand, Indonesia, and Europe. Asia appears to be out-investing the United States in renewable energy (Milken Institute, 2013). There are at least 16 lignocellulosic biofuels biorefineries in the United States at the commercialisation. Essential lessons will be learned for lignocellulosic bio-based materials plants as it is the feedstock pre-treatment that has generated the most significant financial and technical barriers.

The scale of the financial barriers is sobering. For the United States to replace about 20% of petrochemical consumption with bio-based products over the next decade, and capturing a significant portion of the global renewable chemical market in so doing, would require as many as 10 commercial-scale bio-based production plants. This would need about USD 50 billion in capital, most from private investors. However, if the case for new jobs and economic growth is good enough, then there may be justification for government to share some of the financial risk and to spur demand.

For both demonstrator and commercial scale bio-based production plants, the hesitance of investors can be understood:

- For demonstrator plants, the production outputs are generally low, and for all but the lowest volume chemicals, the level of production is not significant enough to influence the market, normally dominated by petrochemical production;

- For commercial scale production, the plants take a long time to build, and come at a high cost. For a petrochemical plant, there is relatively low risk for an investor, with the prospect of modest returns, but over long time scales. Normally the production costs would be met through syndicated bank loans. With a bio-based production plant, however, there is little experience in the market, and the long innovation cycles typical of biotechnology (in the range of five to ten years) are too long for most venture capital investors. Bio-based production can therefore be caught in a typical 'valley of death'.

Direct subsidies to private investments represent a typical incentive for biorefinery schemes (e.g. Gilbertson et al., 2007; Mayfield et al., 2007). These types of subsidies aim at lowering both the fixed costs and the investor risks of new plants, improving the return on investment. While public subsidies are crucial in stimulating biorefinery production, they are also considered to have the greatest level of distortion on production decisions, potentially leading to inefficient outcomes. Therefore, careful oversight and policy flexibility are required to try to maximise the benefits of such public investments.

Public-private partnerships (PPPs) and innovative finance mechanisms

Perhaps the biggest hurdle to getting industrial biotechnology from the laboratory to full-scale production is the gap in investment funding (Shott, 2010). Loan guarantees can be used to give investors confidence that governments are strongly behind bio-based production, and willing to create a long-term stable policy regime. The costs to governments would be lower at the demonstrator plant phase, and this is where the investment need is more acute: success at demonstrator phase is more likely to give industry the confidence it needs to follow on to full-scale.

JTI-BBI

The European Union Joint Technology Initiative "Bio-based and Renewable Industries for Development and Growth in Europe" (JTI BBI) is being launched. This is a PPP themed on the bio-based industries and is being established in cooperation between the European Commission and the Bio-based Industries Consortium (BIC). The consortium currently brings together almost 60 European large and small companies, clusters and organisations across technology, industry, agriculture and forestry sectors. They have all committed to invest in collaborative research, development and demonstration of bio-based technologies. This PPP is an instrument to overcome the innovation valley of death described above. The total budget will be EUR 3.8 billion (including in-cash and in-kind contributions). In addition, industry has committed to invest EUR 2.8 billion in the establishment of large demonstration and flagship plants.[29]

A PPP waste biorefinery at Vero Beach, Florida

An example of a waste biorefinery financed through a PPP is the Vero Beach, Florida facility.[30] At full production, this waste biorefinery is expected to produce 8 million gallons of advanced cellulosic bioethanol and six megawatts (gross) of renewable power using renewable biomass including garden, vegetative, and agricultural wastes. The waste material goes through a gasification process to create synthesis gas, or syngas. The heat recovered from the hot syngas is fed into a steam turbine and is used to generate renewable electricity. The renewable electricity powers the facility and the excess electricity is expected to power as many as 1 400 homes in the Vero Beach community. A relatively small facility, it has 60 full-time employees and provides USD 4 million annually in payroll to the local community. This example of a PPP involves Ineos Bio and New Planet Energy, Florida, with the US DoE (providing a USD

50 million cost-matched grant from the Recovery Act, 2009)[31] and the USDA (providing a USD 75 million loan guarantee).

Toulouse White Biotechnology

Toulouse White Biotechnology (TWB)[32] 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.

The UK Green Investment Bank

The United Kingdom Green Investment Bank plc. (UKGIB) is a funding institution created in 2012 by the government of the United Kingdom to foster private sector investment in projects related to environmental preservation and improvement. A non-partisan, House of Commons committee on climate change stated that, since traditional sources of capital for investment in green infrastructure (utility companies, project finance and infrastructure funds) could not provide even half the amount needed by 2025, there would be a funding gap of hundreds of billions of pounds (Sterling) that needed to be covered by the state budget (House of Commons, 2011).

The bank differs from a typical 'fund' in that it must not just disburse government money, but as a 'bank' it should be able to raise its own finance and fill a gap in the market for government-backed bonds, bring in banking expertise and offer a range of commercially-driven interventions - loans, equity and risk-reduction finance. To make such a mechanism viable, it must attract private sector investment and operate commercially without being influenced directly by the government. The UKGIB is mandated to operate as a 'for profit' bank and became operational in October 2012, with GBP 3 billion of United Kingdom taxpayer capital.

Projects that the UKGIB can invest, into many of which bio-based production falls, include:

- Large energy de-carbonisation projects;
- SMEs;
- Innovation;
- New technologies and R&D;
- Community scale action;
- Investment priorities; and
- Nuclear power.

Biodiversity-related finance mechanisms

The OECD recently published work on the opportunities for scaling-up finance for biodiversity across six so-called 'innovative financial mechanisms' (OECD, 2013b), as classified by the Convention on Biological Diversity (CBD). These are:

- Environmental fiscal reform;
- Payments for ecosystem services;
- Biodiversity offsets;
- Markets for green products;
- Biodiversity in climate change funding; and
- Biodiversity in international development finance.

Again, it is possible that bio-based production could fall under several of these mechanisms.

Rural infrastructure requirements

Given that much attention is being given to rural biorefining, there will be a need for careful examination of infrastructure development – provision, upgrading and maintenance of road networks, electric lines, power generation and transmission, communication systems (telephone, internet), energy supply and delivery systems (e.g. heating and cooling) – financed in many countries usually by direct public investments or public subsidies.

Even existing rail networks may be overwhelmed by the volume of products to be transported. In its analysis of transportation requirements associated with the *Renewable Fuels Standard*, the USDA estimated 15 billion gallons per year of fuel transported out of the Midwest would require more than a threefold increase in rail freight over current levels (ESAI, 2009). Building new transport infrastructure in rural environments is often met with public opposition.

Pipelines deserve special mention due to the difficulties in getting them built. In addition to pipeline construction, facilities would have to be built to store and aggregate fuel for transport through the pipeline. Whilst bio-based chemicals should not be made in such volumes that require dedicated pipelines, integrated biorefineries will also make fuels. Pipelines are the most efficient way to transport fuels, but there are three particular problems to be considered by policy makers.

1. In most regions, the bio-based industry is still relatively small and dispersed. If that situation is predicted to continue in any given country, then relying on rail and road transport is the obvious solution.

2. In the case of ethanol, due to its water solubility, it creates additional engineering problems for pipeline construction, compared to the pipelines developed for petroleum fuels. This inevitably makes them expensive.

3. Pipelines are very high-risk business ventures, and there are many political issues to be faced. As a result, they would only be successful in countries where very large ethanol production or demand is envisaged.

Education

Bioeconomy strategies from several countries recommend a key area of action to be investments in research, innovation and skills.[33] The creation of human capital in terms of knowledge and competences is a typical public function provided through the education system (e.g. college and university degrees). Higher education is boosted by funding R&D activities (e.g. post-doctoral degrees, university spin-offs, and internship programmes).

Watkinson et al. (2012) reviewed current provisions in bioenergy at Masters and PhD levels across the 27 members of the European Union (EU27) plus Norway and Switzerland. This identifies a very active and expanding bioenergy education provision. Sixty-five English-language Masters courses in bioenergy (focusing either completely on bioenergy or with significant bioenergy content or specialisation) were identified. They also identified 231 providers of PhD studies in bioenergy.

In the case of bio-based production, coordination with industrial sectors is required in order to tailor the education programmes with long-term strategies, since the risk of incurring unnecessary competences, thus leading to under-employment, is highly relevant. In Europe, enrolment in bioenergy 'Masters' courses has been quite low, suggesting that there is an oversupply of courses and that course organisers are being optimistic in their projections. The educational needs for bio-based production are different, more diverse, multidisciplinary and involve the difficult interface of biological sciences and engineering disciplines. Modern bioeconomy is largely based on knowledge and innovation in biosciences, together with other technologies such as engineering, chemistry, computer science and nanotechnologies.[34] Given the experiences with bioenergy, more thought and planning needs to be given to the provision of this education.

There has long been a shortage of an educated workforce in biochemical engineering (what could be described as biotechnology process engineering or bioprocess). Currently the processes used in bio-manufacturing are technologically immature compared to process engineering in other industries. There is a need to attract students who otherwise would become chemical engineers because they need similar skills in mathematics and materials science. The link to chemical engineering is inextricable: this requires the training of a new cadre of engineers and scientists for joint chemical–biochemical production (Haen et al., 2012).

More widely, the industry will also need a workforce that can balance technical knowledge with more business skills, such as entrepreneurship, venture financing, management of intellectual property and product development and life cycle management. One way to manage this is intensive summer educational programmes for students on science or engineering curricula. Another may be the provision of dedicated MBA programmes. The traditional MBA is unsuited to the biotechnology industry generally. Theories of business administration have their roots in commerce, which has in past been focused on non-technological issues (Lambert, 2004). The pace of change of technology in the biotechnology sector suggests that a different model would be more optimal.

Skills and training

A survey was conducted by the International Labour Organisation (ILO, 2011) to understand the skill change dynamics, and how well national training systems are anticipating and responding to the needs of a green economy. The survey reveals that skill shortages already pose a major barrier to transition to green economies and the creation of green jobs, a trend this is likely to be exacerbated in the future.

Social policies aimed at building professional skills may play a crucial role in addressing young workers or reconverting unemployed workers toward the new bio-based production industry. The OECD country dilemma of loss of fossil fuel refining capacity presents an opportunity for the skilled workers in these refineries. Retraining in bio-based production would save some of the loss of these skills from OECD countries. Typically, the destination of these workers would be the Middle East, where refining capacity is increasing. However, they already possess many of the skills required in biorefineries (e.g. process engineering, health and safety, maintenance), and indeed many would make excellent trainers.

An interesting training model is the National Institutes model in Ireland, primarily funded by the government of Ireland through the inward investment promotion agency, the Industrial Development

Agency (IDA), which is also responsible for the attraction and development of foreign investment. One of these is a dedicated facility for training in bioprocessing (the National Institute for Bioprocessing Research and Training, NIBRT).[35] For a small country, Ireland has a large pharmaceuticals sector. NIBRT provides a "one stop shop" for bioprocessing training requirements. The institute builds unique training solutions for clients, ranging from operator through to senior management training, and training can be delivered in a realistic GMP-simulated, operational manufacturing environment. This type of environment is not one found typically in universities, and is more appropriate for the training of industry professionals. Equally, such a facility could be used by undergraduate and 'Masters' programmes to give students exposure to industry working conditions.

Market-introduction measures

There are existing models for market introduction and public procurement instruments. Public procurement programmes, such as the USDA Biopreferred[36] voluntary labelling and procurement programmes, have the potential to be major market drivers for bio-based chemicals. The United States government and its contractors are required by law to purchase products that are bio-based. The USDA BioPreferred programme identifies which types of products must be afforded this procurement preference. It has two major initiatives:

1. Product labelling – the USDA certifies and awards distinctive labels to qualifying products to increase consumer recognition of bio-based products. As a part of this process, the minimum bio-based content is specified to meet certification criteria;

2. Federal procurement preference – the USDA designates categories of bio-based products that are afforded preference by Federal agencies when making purchasing decisions.

As of December 2012, the USDA had certified 900 bio-based products in more than 100 product categories.[37]

Similarly, in Europe the Lead Market Initiative (LMI) Ad-hoc Advisory Group for Bio-based Products made various recommendations (OECD, 2011c):

- Legislation promoting market development, including total CO_2 equivalent emissions offsets, indicative or binding targets, and tax reductions for sustainable bio-based products;

- Product-specific legislation e.g. allowing bio-based plastics to enter composting, recycling and energy recovery schemes;

- Legislation relating to biomass to guarantee quantity and quality of feedstocks at good prices;

- Encouragement of green public procurement for bio-based chemicals;

- Standards, labels and certification that help verify claims such as biodegradability and bio-based content, that will promote market uptake; and

- Financing of research, and the continued efforts to build demonstration plants via public-private initiatives.

A key achievement of the LMI, which will underpin the future sustainability of the bio-based products sector, is the development of European level standards, the lack of which had been identified as a factor

hindering market uptake both by consumers and in public procurement (Centre for Strategic and Evaluation Services, 2011).

Standards and labels

Standards for bio-based products at international level (e.g. on bio-based content, biodegradability, sustainability and functionalities) will ensure their consistency across sectors. Standards are also central for the development of labels for bio-based products. To be comparable and reliable, sustainability assessments for bio-based products need to be standardised and certifiable. Sustainability criteria for bio-based products and biofuels should be comparable and take into account factors such as the calculation of GHG emissions and criteria for sustainable biomass production. Life cycle assessments can contribute to improving the sustainability of products and processes. They should be clear, objective, science-based, easy to handle and implement and do not add significant costs to the development of innovative products or hinder market access for SMEs. However, the LCA procedures that have been used to support biofuels production in Europe have been criticised (ANEC, 2012). LCA procedures for bio-based chemicals and especially bioplastics are more complex still, particularly due to end-of-life concerns (OECD, 2013a).

In the same manner that RFS2 set GHG emissions savings standards along with volumetric mandates for biofuels, environmental targets for bio-based materials may be possible. This might have the effect not only of encouraging the development of the most effective bioplastics, but would also deter early investment in bioplastics with poorer environmental performance. Narayan and Patel (2003) have made an attempt to specify such targets: they recommended that, relative to their conventional counterparts, biopolymers and natural fibre composites should:

- Save at least 20 MJ (non-renewable) 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 data produced by Weiss et al. (2012) showed that a range of bio-based materials saved, on average, 55 +/- 34 MJ non-renewable energy and 3 +/- 1 kg CO_2 per kg material, thereby easily meeting the suggested targets of Narayan and Patel.

Labelling can play an important role for the commercialisation of bio-based products, providing consumers with clear information on the environmental performance of the products and guiding their purchasing behaviour towards sustainable choices. Labels can also be critical for the uptake of bio-based products by green public procurement. In view of the proliferation of national and international labelling schemes, there are benefits to be attained by associating bio-based products with a successful existing scheme that has a harmonised and standardised approach. A European Union example is the European Ecolabel. Although its criteria are not fully congruent with those of a sustainability assessment under European industrial policy, it already includes products with renewable carbon content under various product groups (e.g. lubricants and detergents). Creating additional product groups covering bio-based products could be considered, as well as the further development and improvement of the Ecolabel criteria. However, currently there are 439 ecolabels within the Ecolabel Index,[38] and this is creating confusion.

Specialist SME support

Bio-based products create entirely new markets or enter markets dominated by well-established fossil-derived chemicals suppliers. This competition with fossil-derived chemicals creates specific challenges for both start-ups and mature companies wanting to enter a bio-based market as either a supplier or a

customer. A specialised support infrastructure for SMEs across regions would be beneficial. It could advise interested stakeholders on the strategic use of instruments (e.g. standards, labels, certificates) and assist with specific LCA and sustainability tools, bio-based eco-design aspects, and provide access to demonstration, testing and certification facilities.

A region-wide approach bringing together suppliers and potential users downstream in the bio-based products value chain would increase the probability of avoiding market failures and earn societal benefits earlier, contributing to a lead market advantage. The BIOCHEM project[39] funded under the European Union Competitiveness and Innovation Programme (CIP) could be looked at as a potential pilot for such services.

Public information provision

The provision of information, by means of information programmes and consumer education programmes at local and national levels, can significantly help to drive the development of new technologies. Without information, people may have a vague and potentially distorted understanding of their novelty, which may obstruct their development (Mayfield et al., 2007). Public information should be tailored to different stakeholders' requirements (e.g. technical details of cropping practices for farmers, risk evaluation for private entrepreneurs, impact on the quality of life for local citizens). Also, 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".

POLICIES SUPPORTING THE DEVELOPMENT OF BIOENERGY

Introduction

This section focuses on policy support for bio-based electricity generation through biomass, though it does not represent a comprehensive review of all relevant material. Subsequent sections offer similar reviews of policy support for liquid biofuels development and policies associated with bioplastics (and biochemicals).

At least 109 countries had renewable power generation policies in place by 2012. Of all the renewable energy sources, biomass offers one hugely strategic advantage. It is the only directly storable renewable energy source, so can be dispatched on-demand, offering significant energy security advantages compared to solar and wind. Despite relatively low energy density (Blaschke et al., 2013), this strategic value of biomass has become a popular focus for bioenergy production.

The main sources of biomass for electricity generation are wood pellets and residues from agriculture and industry (Eurostat, 2012).[40] The importance of wood pellets for large-scale power generation is increasing dramatically, such that many countries have become net importers, (Table 7), as an earlier evaluation predicted (Banse et al., 2008). Wood pellets are imported to the European Union mainly from Canada, the United States and Russia, which together have a total share of over 80% of pellet imports to the European Union.

Table 7. Wood pellet production and consumption patterns in various countries (thousand tonnes)

	Production		Consumption	
Country	**2005**	**2010**	**2005**	**2010**
Austria	440	850	305	660
Denmark	187	180	820	1600
Finland	190	253	55	213
Germany	240	1200	200	1845
Italy	240	750	290	1450
The Netherlands	110	120	487	913
Sweden	1100	1645	1480	2200
European Union	2628	9260	3835	11400

Note: One source has predicted that Europe will be importing 80 million tonnes of solid biomass per annum by 2020 (Cocci et al., 2011).

Source: adapted from Scarlat et al. (2013)

These patterns create different policy requirements for different countries. For example, the Netherlands mainly co-fires wood pellets in large coal power stations for electricity production although it has limited capacity to increase its production of wood pellets, so relies heavily on imports. Key factors to achieve the national targets of the Netherlands have been identified as enhanced technological development and the import of sustainable biomass resources (Hoefnagels et al., 2013). The United Kingdom example puts the situation in sharp focus. If all plants at the planning stage in the United Kingdom are to be implemented, the amount of imported biomass would increase from 1.3 million tonnes in 2010 to 39.1 million tonnes in 2020, an increase of some 29 fold (RSPB, 2011).

Key drivers of bioenergy policy

The most important policy objective for bioenergy policy is reduction in GHG emissions in response to the threat from climate change. This is being addressed by the United Nations Environment Programme (UNEP) via the United Nations Framework Convention on Climate Change (UNFCCC),[41] under which different countries commit to achieving different levels of reduction in their emissions inventory, consistent with a global climate change mitigation target. When providing national inventory returns in line with guidance from the Intergovernmental Panel on Climate Change (IPCC),[42] countries are obliged to report the emissions associated with solid biomass as well as those associated with fossil fuels. There is a significant conundrum here: the IPCC default Tier 1 emission factors show emissions from solid biomass to be *higher* than for bituminous coal, and only marginally lower than for lignite (IPPC, 2006).

This conundrum is reconciled on the basis that this biogenic carbon was relatively recently sequestered, and therefore there is no net increase in the long-term atmospheric GHG burden (compared to fossil fuels, where the carbon was sequestered millions of years ago). However, in reality this is by no means necessarily so. For example, it is highly likely that there are inputs of non-renewable energy in order to access the biomass. Diesel is usually used to drive the machinery that harvests and transports the wood. The production process itself may generate GHG emissions; for example, emissions of nitrous oxide from soil on which crops are grown. The result is that the actual GHG reductions achieved by bioenergy systems are highly variable between feedstocks, technologies, and energy demand, and therefore cannot be considered equal when it comes to considering the key policy objective of reducing GHG emissions.

The over-riding objective of reducing GHG emissions introduces at least three other policy objectives (Thornley, 2012):

1. To grow biomass to sequester as much carbon per unit of land as possible (which depends on geographic location and species);

2. To ensure that bioenergy displaces more carbon-intensive forms of fossil fuel energy; and

3. To minimise the additional emissions associated with processing, transporting and transforming biomass to suit customer demands.

Policies commonly applied to bioenergy for electricity generation

In Europe, some countries have a longer history of bioenergy use than others do, which affects the types of policies that are applied to support the bioenergy sector. However, a small number of policy options have been used frequently by different countries. At first sight, a "command and control" instrument may appear attractive i.e. setting a maximum limit on the amount of GHG emissions per unit of energy produced, and then monitoring progress. However, demonstrating the actual GHG savings for different systems is very labour- and time-intensive, and the results often remain highly uncertain. The approach is also contrary to the deregulated 'free market' concept on which most national electricity supply systems are now based.

Investment subsidies and new technology support

This is a financial contribution from a government or other central funding body that provides a specified level of financial support for the capital investment associated with a new project or installation. Compared to other renewable energy forms, biomass differs in this need. Wind and solar, for example, have high initial capital costs but much lower on-going operational costs. With biomass, there is an on-going fuel cost. In countries that are new to bioenergy generation, investment subsidies have helped initially to stimulate the sector, but these must be long-term to be successful. In Germany, investment

subsidies were only effective when combined with fixed price (feed-in) tariffs (Thornley and Cooper, 2008).

Feed-in tariffs (FITs)

Fixed prices or feed-in tariffs are specified (normally premium i.e. higher than prices paid for conventional fossil fuel electricity) prices paid to all producers of a particular form of energy for a defined period. When bioenergy centres upon electricity generation, the use of biomass-based technologies is relevant to the very common strategy of FITs. When applied across all renewable energy sources, the FIT should have the benefit of bringing on stream a variety of different technologies, rather than simply the lowest cost renewables (an important consideration in energy security). However, this also runs contrary to the free market, which should be favouring the most cost-effective option. The mechanism also presents no incentive for the producers to reduce their costs to encourage long-term efficiency gains. Without efficiency gains, competing with fossil fuel electricity in the long run will not be feasible.

Germany used FITs widely to support bioenergy, but initially results were not encouraging. The fixed prices offered wind power 90% of the average utility rate for consumers, but biomass producers received only 80% (Sijm, 2002), demonstrating the need to get the level correct, which is not necessarily easy. It was only later that sustained increases in capacity occurred. This is likely to reflect the fact that longer-term price commitments (20 years) were available under the amended fixed-prices legislation, facilitating new development commitments.

Green certificates

Green certificate mechanisms generally place an obligation on electricity supply companies to produce a specified fraction of their electricity from renewable energy sources, earning a certificate, which they then pass to the regulatory body to demonstrate compliance. It is effectively a quota-type system focused on mandating a minimum quantity of low carbon energy from suppliers. This mechanism takes into account that some suppliers will not finance investment in alternative forms of energy, thus they are able to buy certificates from other companies who have succeeded in doing so. A market of certificates is thus created, and suppliers may trade their certificates to gain a higher price from those who have not succeeded.

To date, green certificate schemes have not been very successful in promoting bioenergy (Thornley, 2012). The main reason for this is that the schemes are usually ‘technology blind’ and so treat all renewable electricity sources as equal and pay equally for them. In reality, bio-based electricity schemes often cost more than other more established forms of renewable energy and so the premium payment offered by these schemes is insufficient to make project development commercially viable. This has been the case in the United Kingdom. However, Italy has achieved success with green certificates, probably due to the specifics of the scheme (Farinelli, 2004).

Others

The full suite of policy measures used to support bioenergy also includes energy and carbon taxes, complemented with quota obligations, tax reduction and exemptions, investment subsidies and FITs for renewable electricity, support for technology development, and suitable conditions for bioenergy deployment. Energy and carbon taxes play a crucial role in that they are used to support the revenue requirements for other instruments, thereby limiting the costs to governments and end-users. Whatever mix is used, it is crucial that they are deployed consistently over the long term.

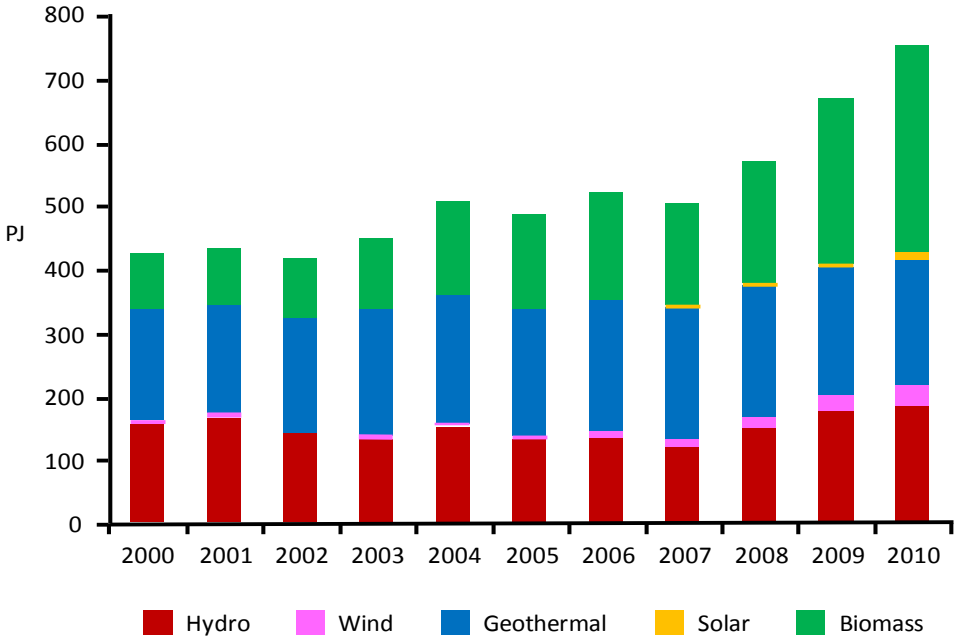
Bioenergy in Italy

The case of bioenergy development in Italy is included to illustrate some innovative support mechanisms and to show how the importance of bioenergy has grown in recent years. Italy was one of many countries with a limited history of biomass use for electricity generation. Two important measures that helped change this situation were the specific targeting of the agricultural sector to facilitate expansion of bioenergy, and the deployment of substantial investment subsidies.

The contribution of different energy sources to the Italian energy mix has changed towards increasing the relative contribution of biomass, wind and solar in the renewable sources category. Biomass has become the dominant source of renewable energy, with a contribution of about 43% of total renewable energy by 2010 (Figure 8), and is expected to provide the highest contribution in the future. In the space of ten years (2000-2010), the total installed biomass plant capacity in Italy grew from 686 MWe to 1953 MWe.[43]

Substantial investment subsidies (to initiate growth), combined with technology-blind trading certificates (to perpetuate growth), have been the most effective measures encouraging the development of new capacity and the utilisation of existing capacity in Italy. In addition to the income from the sale of green certificates, the plants can sell the electricity fed into the grid through the usual instruments for selling electricity. Gestore Servizi Energetici, the regulator of the system, will buy back, at a pre-established price, those green certificates not used to fulfil the obligation (Scarlat et al., 2013).

Figure 7. The growth of renewable energy consumption in Italy



Source: Eurostat (2012), http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/

Efforts to stimulate investment in bioenergy in Italy have a relatively long history, including the introduction of FITs in 1992 (Table 8). In 2012, a new scheme offering a better deal for small plants was introduced, since the original FIT regime tended to benefit larger firms disproportionately. For plants producing less than 1 MW, the FIT includes a provision guaranteeing the purchase of electricity produced. For plants larger than 1 MW, the FIT does not include a similar guarantee.

Table 8. Timeline of early policy support for bioenergy in Italy

Year	Policy initiative
1991	De-regulation
1991	Investment subsidies
1992	Feed-in tariffs
1999	Carbon tax
2000	Investment subsidies
2000	Tax credits
2001	Green certificates

Source: Adapted from Thornley and Cooper (2008)

Two other very general lessons were learned in Italy:

1. Continuity of policy instruments is important and withdrawal of support schemes is likely to impact negatively on the market, as was the case post-1996;

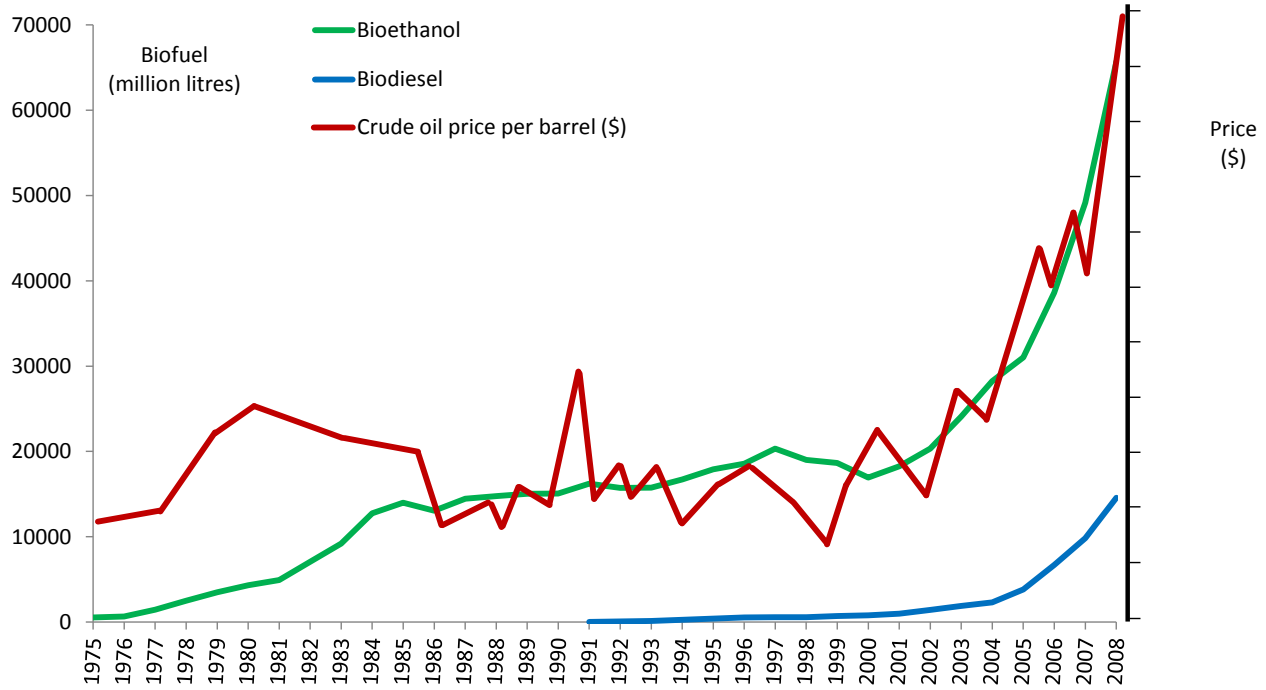
2. Investor confidence is engendered once a pilot scheme becomes established practice.

POLICIES SUPPORTING THE DEVELOPMENT OF LIQUID BIOFUELS

Introduction

The largest growth in CO_2 emissions between 1970 and 2004 (an overall increase of 70%) came from power generation and road transport (Barker et al., 2007). Partial substitution of fossil-derived transport fuels with biofuels represents one option to address the road transport emissions dilemma, but the degree of substitution remains contentious. From around 2005, there has been a dramatic increase in liquid biofuels production. Global production of fuel ethanol more than doubled between 2005 and 2010 (FO Licht, 2010b) (Figure 9). In Europe, there has been a larger emphasis on biodiesel production, due to the prevalence of small diesel engines used in cars in Europe (ESAI, 2009). During the same period (2005-2010), global biodiesel production more than quadrupled (FO Licht, 2010a).

Figure 8. Price trends in crude oil, bioethanol and biodiesel



Source: Crude oil prices from BP/Bloomberg. Bioethanol and biodiesel volumes from Sorda et al. (2010)

The driving forces behind this increase are several, amongst them energy security, climate change mitigation and rural regeneration. What is often overlooked in the many debates over bioethanol as a biofuel is that it also plays an extremely important and growing role as a replacement for methyl tertiary butyl ether (MTBE) as a fuel oxygenate. Because of multiple environmental concerns over MTBE, it was first banned in California and New York State in 2004, and many other states in the United States have also banned it. The US Energy Policy Act of 2005 did not include a provision for shielding MTBE manufacturers from water contamination lawsuits. The lack of MTBE liability protection has resulted in a switchover to the use of ethanol as a petrol oxygenate to boost octane number.

Since then a ban on MTBE usage in the fuels industry has been adopted in many countries in Europe and Asia, leading to steeply falling demand levels across the world (Merchant Research & Consulting,

2012). With increasing policy support for transport biofuels in Asia, the role of ethanol as an oxygenate is likely to increase. Despite being overlooked, this is a critical role for bioethanol to fulfil. By 2011, liquid biofuels were contributing about 3% of the total of global road transport fuels, more than any other renewable energy source in the transport sector.

Main categories of support for liquid biofuels

The single most important policy goal is to make sure the price of bioethanol is lower or equal to petrol for a long time, and many different support mechanisms exist across the spectrum of the value chain that can help biofuels production and consumption to achieve this over-riding incentive. In broad terms, three main categories of support mechanisms can be identified (OECD, 2008).

- *Budgetary support measures*, either as tax concessions for biofuel producers (refineries), retailers or users, or as direct support to biomass supply, biofuel production capacities, output, blending, specific infrastructure or equipment for biofuel users. All these measures directly affect the public budget either in the form of forgone tax revenues or of additional outlays.
- *Trade restrictions*, mainly in the form of import tariffs, result in higher domestic biofuel prices. These measures impose a cost burden on domestic biofuel users and limit development prospects for alternative suppliers.
- *Blending or use mandates* require biofuels to represent a minimum share of quantity in the transport fuel market. While these measures generally are revenue-neutral for public budgets, the higher production costs of biofuels result in increased fuel prices for the final consumer.

On a global basis, it is the first and third categories that are the most significant, and which offer the strongest support to the growing industry.

Incentives through excise and taxes

Incentives on taxes and excise reduction to make the price of bioethanol competitive with other fuels are most likely to enable it to achieve a market breakthrough. The challenge is that this is a national matter and that it directly affects the national treasury. Moreover, achieving these kinds of measures takes time and endurance. As examples, Germany, Spain and Sweden have used national excise measures to make bioethanol more competitive at the pump. On the contrary, Italy, the Netherlands and the United Kingdom have not.

Trade tariffs

These are designed to protect domestic production from cheaper imports until such times as the domestic industry is competitive. An example is the *Import Duty for Fuel Ethanol*, administered by the US Customs and Border Protection (CBP), which expired at the end of 2011. A duty of 54 cents per gallon of ethanol (for fuel use) applied to imports into the United States from most countries.

Production and blending mandates

Mandates have proven easier to introduce, but their use is still controversial. However, production mandates are more revenue-neutral than tax and excise reductions (Lapan and Moschino, 2012).

In 2012, the Biofuels Digest released its annual review of biofuels mandates, stating that there were 52 countries with mandates or targets,[44] mostly in the EU-27, but also 13 in the Americas, 12 in Asia-Pacific and 8 in Africa (see Table 9 for OECD and BRICS countries obligations/mandates). In addition, as

of early 2012, fuel-tax exemptions and production subsidies existed in at least 19 countries. Governments are also paying increasing attention to biofuel sustainability and environmental standards. A global biofuels map with updates on mandates is available from the Global Renewable Fuels Alliance.[45]

As of mid-2011, mandates in place around the world called for a biofuels market of at least 220 billion litres by 2022, with expected demand to be driven primarily by Brazil, China, the EU, and the United States.

Table 9. Biofuels mandates in OECD and BRICS countries*

Country	Biofuels obligation/mandate	Biofuels blending mandate/target	Comments
OECD			
Australia	State/provincial	Indicative target of 350 million litres of renewables by 2010	NSW: E4 and B2; Queensland: E5 opposition caused the Queensland mandate to be shelved late in 2011
Austria	National	2.5% of renewable fuels in transport fuel since 2005	Mandatory target of 5.75% by 2010
Belgium	National	E4 and B4	
Canada	National	National and five provinces: E5 and B2	The Canadian Renewable Fuels Association has assessed the grand total of annual positive economic impact of renewable to fuels to be USD 2.0 billion
Chile		Targets, E5 and B5	
Czech Republic	National	Blending mandates	3.5% for petrol, 4.5% for diesel (Jan 2008)
Denmark	National	Non-mandatory target	To blend 5.75% of renewable transport fuels by 2010
Estonia	National	Non-mandatory target	To blend 5.75% of renewable transport fuels by 2010
Finland	National	Mandate	At least 5.75% biofuels by 2010.
France	National	Mandate	10% biofuels into fossil fuels by 2015
Germany	National	Mandates, E10	E5.25 and B5.25 in 2009; E6.25 and B6.25 from 2010 through 2014. Overall biofuel mandate – 8% by 2015
Greece	National	Non-mandatory target	To blend 5.75% of renewable transport fuels by 2010
Hungary	National	Non-mandatory target	To blend 5.75% of renewable transport fuels by 2010
Iceland			No information available
Ireland	National		
Israel			No information available
Italy	National	Targets, E1 and B1	Mandatory target: 2% of sales by 2008, 3% in 2009
Japan		Non-mandatory target	50 million litres of biofuels by 2011 (domestic production)

Korea	National	B2.5	This is a 2012 increase from B2, and is expected to increase demand for imported Malaysian palm oil for fuel use
Luxembourg		Non-mandatory target	To blend 5.75% of renewable transport fuels by 2010
Mexico		E2 (in Guadalajara)	To be extended to Mexico City and Monterrey during 2013
Netherlands	National	Mandate	5% of biofuels blended by 2010 (percentage based on energy content)
New Zealand		Mandatory target	To blend 3.4% of renewable fuels in transport fuels by 2012. The biofuels obligation was replaced by a biodiesel subsidy
Norway	National		
Poland	National	Obligatory target	To blend 6.65% by 2012, 7.10% by 2013
Portugal	National	Mandate	To blend 1.15% biofuels by 2005, but also non-mandatory target of 5.75% in all transport fuels by 2010
Slovak Republic		Non-mandatory target	To blend 5.75% of renewable transport fuels by 2010
Slovenia		Mandate	To blend 5% of biofuels by 2010
Spain	National	Mandate	To blend 5.83% biofuels by 2010
Sweden	National	Mandate	Biofuels must make up 5.75% of total petrol and diesel consumption for transport by 2010. Sweden targets a complete phase-out of fossil fuels in transport by 2030
Switzerland	National		A provision to use biogas with a tax reduction
Turkey	National	Mandate	At least 2% bioethanol from 1/1/2013 and 3% by 1/1/2014. Excise duty reduction of 2% for blenders selling ethanol-blended fuels
United Kingdom	National	Mandate (obligation)	5% of all transport fuels to be biofuels by 2010
United States	National	National, 10 states	RFS2in 2013 targets: Biodiesel - 1.3 billion gallons; Advanced biofuels – 2.0 billion gallons; Cellulosic biofuels – 3.45-12.9 million gallons ; Total renewable fuels – 15.2 billion gallons

European Union	International	5.75% mandate in place, proposed to increase to 10% by 2020	RED: Directive 2009/28/EC EC now proposes to reduce biofuels targets from 10 to 5%, and to introduce iLUC calculations on acceptable feedstocks. An increase from 5 to 10% would have to come from non-food feedstocks. The EU biofuels industry has responded with hostility, although the algae producers applaud the change
BRICS			
Brazil	National	Mandate E18-25 and B5	Brazil aims for a B10 by 2014, and B20 by 2020
Russia			No information available
India	National	E10	20% biofuel mandate by 2017
China	National	E10 in 9 provinces	10% ethanol blending mandate by 2020
South Africa	National	Future E5, B2	An E10 mandate was introduced in 2012

* *Table Note:* The B and E references in this table refer to the % of biodiesel or ethanol in a fuel blend respectively. For example, E10 refers to a blend of 10% ethanol with 90% petrol.

Several governments revised policies in 2011. In Europe, Belgium extended its existing B4[46] and E4 blending mandates, and Spain increased its 2011 biofuels mandate from 5.9% to 6.2% (in terms of energy content), rising to 6.5% for 2012–13; Bulgaria, Finland, Poland, and Italy followed suit. In Australia, New South Wales postponed its biodiesel mandate increase (from B2 to B5) due to a lack of sufficient local supplies to meet the proposed target.

Sources: BNDES and CGEE (2008); GAIN Report (2008); Global Subsidies Initiative (2007, 2010); OECD (2008); REN21 (2009, 2012); RFA (2008); USAID (2009); World Bank (2010); Worldwatch Institute (2006).

Other biofuels incentives

Support is possible throughout the bioethanol value chain (Figure 10). In this section, some of the lesser-known incentives are summarised, demonstrating the range of incentives that can be applied to biofuels. Most, however, are not applicable to bio-based chemicals and plastics.

Intermediate output subsidies

These intermediate inputs include goods and services that are consumed in the production process. The largest of these are subsidies to producers of feedstock crops used to make biofuels, such as oilseed rape for the production of biodiesel.

Value-adding factors

These include subsidies affecting the purchase and use of the capital goods and labour employed directly in the production process, and the purchase and use of land for plant construction. Some countries provide capital grants or subsidised loans for these purposes. In some countries, public authorities have also participated in the financing of demonstration plants. These types of subsidies lower both the fixed costs and the investor risks of new plants, thereby improving the return on investment.

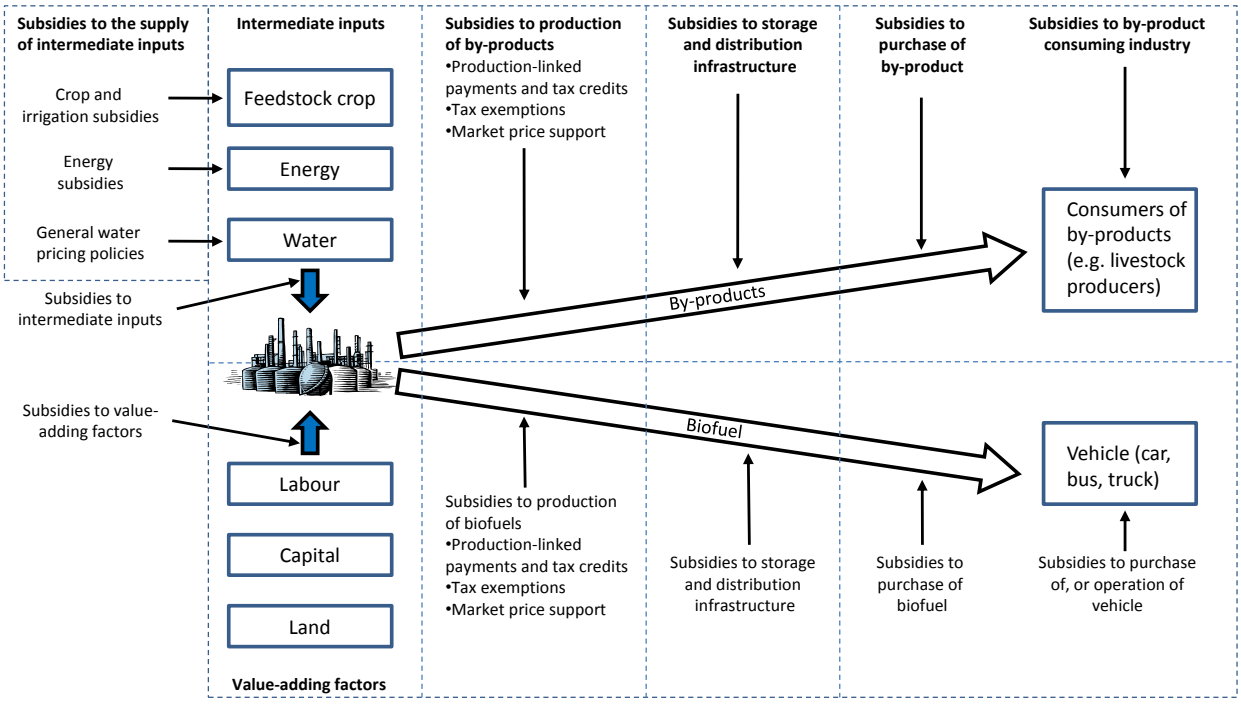
Incentives affecting distribution

Most incentives affecting distribution off compensation for the costs involved in modifying service stations in order to offer bioethanol. The United States *Alternative Fuel Station Credit*, which expired at the end of 2011, allowed for a qualified taxpayer to take a 30% credit for the installation of alternative fuel infrastructure (including E85), up to a ceiling of USD 30 000 (Yacobucci, 2012).

Incentives affecting vehicles

Most of the incentives affecting vehicles relate to green procurement. Very few countries offer straight financial incentives for flex fuel vehicles (FFVs), Sweden being an exception. Private companies can also organise effective incentives: Ford-Netherlands has offered an environmental benefit for FFV buyers and Volvo offered eco-driving training to FFV buyers. Congestion charging is another important instrument to stimulate the use of clean vehicles and bioethanol. However, for incentives affecting vehicles, it is important to be able to define what the policy makers recognise to be a clean vehicle, and this is by no means universally agreed.

Figure 9. Subsidies through the value chain in biofuels production



Source: adapted from Global Subsidies Initiative (2007)

Some international examples

The longest history of nation-wide bioethanol implementation is to be found in Brazil. However, it was the explosion in bioethanol production in the United States in this century that stimulated the levels of international production and trade that are now apparent. The European Union approach has been to set targets through a biofuels directive and to call for national action plans. The approach by Sweden is interesting due to the innovative use of demand-side policies, allied to a very demanding policy goal of ridding the country of oil imports. A more comprehensive review of global biofuels policy is given by Sorda et al. (2010).

Brazilian bioethanol support

Brazil is a special case due to a long history (several decades) of policy support for bioethanol since the inception of the *Pró-Álcool* policy after the first oil shock. Brazil used to import all of its petrol and crude oil from abroad, at an annual cost of USD 600 million. In 1973, with the first oil shock, imports rose to more than USD 4 billion annually, contributing greatly to a deficit in hard currency and, as in many other countries, the economy was badly damaged (Moreira & Goldemberg, 1999). Inflation ran at 15.5% in 1973, and 34.5% in 1974. In November of 1975, the federal government established the *National Alcohol Program* (*Pró-Álcool*) by decree, and set production goals of three billion litres of ethanol by 1980 and 10.7 billion litres by 1985 (Goldemberg, 2009).

Experience there has shown that incentives are required for a long time before a self-sustaining market can be achieved. By 2004, ethanol in Brazil had become economically competitive with petrol based on international prices for oil (equivalent to USD 40 per barrel) (Goldemberg, 2008). By 2007, the Brazilian ethanol programme provided nearly 1 million jobs, and cut 1975–2002 oil imports by a cumulative undiscounted total of USD 50 billion (Wonglimpiyarat, 2010). As of 2011, there were 490 sugar cane ethanol plants and biodiesel plants in Brazil (Brazil Biotech Map, 2011). Brazil is today the world's second-largest producer of bioethanol and the world's largest exporter. All this has been achieved with a mix of supply- and demand-side policies.

Incentives proved to be very important in creating a market breakthrough for ethanol cars. The perspective for long-term incentives is very important. However, these financial incentives should, of course, be transient and should be phased out when the market is fully developed.

Typical incentives that have been used in Brazil are (Vermie and Akkerhuis, 2009):

- Reduction in registration fees for ethanol vehicles;
- Mandatory alcohol vehicles in the official public fleet (the 'green fleet');
- Tax exemptions for taxis;
- A mandatory blend of anhydrous alcohol in petrol from 20% in 1975 up to 30% in 2003;
- A minimum blend of 3% anhydrous alcohol in diesel; and
- A new FFV green fleet, including taxis and government-owned cars.

The Brazilian car manufacturing industry, under government pressure, developed flex-fuel vehicles that can run on any proportion of petrol and hydrous ethanol. The consumer is therefore able to buy either petrol or ethanol, depending on prices. Today Brazilians are driving about 24 million automobiles. Most of the pure ethanol cars on the road – 2.8 million in 2000 – have been retired. Already seven million flex-fuel cars are on the road and their numbers are increasing rapidly (Goldemberg, 2009).

The success of the *Pró-Álcool* programme is reflected in the importance that sugar and ethanol production play in the Brazilian economy. The two industries account for 3.6 million jobs and 3.5% of GDP, while ethanol production alone consumes 50% of the total sugar cane supply (Sorda et al., 2010).

Japan

The Japanese government is promoting biofuel programmes to deal with energy security and environmental problems, to increase farm income, and to revitalise rural areas. The Kyoto Protocol provides the biggest incentive to promote biofuel production and utilisation in Japan (Koizumi, 2013).

Although several ministries promote biofuel programmes in Japan, their incentives and background policies differ.

When international food and agricultural products prices surged from 2006 to 2008, there was strong criticism against expanding agricultural product-based biofuel production in Japan. Therefore, in order to increase domestic biofuel production, it became necessary to produce biofuel using cellulose materials and unused resources. The crucial factors for expanding bioethanol markets are technological innovation and the technology to produce biofuel efficiently from cellulose material and algae. The price differences (Figure 11) between petrol and domestic bioethanol prices, and between imported bioethanol prices and domestic bioethanol prices, are crucial challenges to increasing biofuel production in Japan.

Figure 10. Bioethanol production costs in Japan

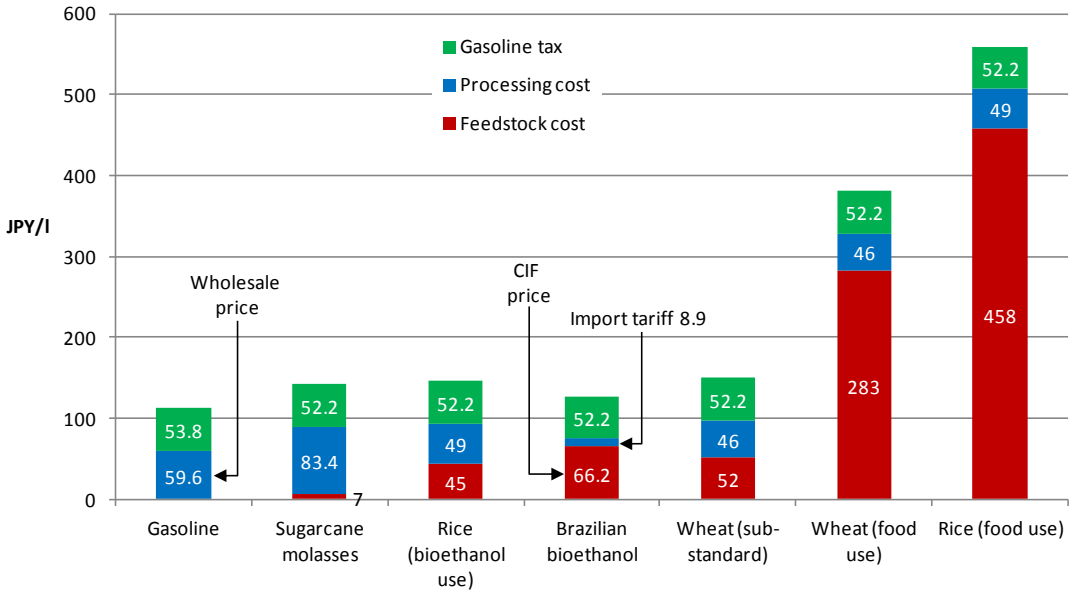


Figure Note: Production cost includes capital cost and variable cost. Retail price includes transportation cost and consumption tax. The wholesale price of petrol is the average March 2010 price from the Oil Information Centre. b) The Brazilian bioethanol CIF price is the average March 2010 price from trade statistics. The custom tariff is 13.4%. CIF = cost, insurance, freight.

Source: Koizumi (2013)

Although the Japanese government plans to increase domestic biofuel utilisation, it is estimated that Japan will have to depend on imported biofuel to satisfy national targets. In line with this trend, Japan has to establish sustainable criteria for biofuel that determine the limitations of GHG emission, and pay close attention to biodiversity, food availability, and social consequences. To realise this, further research and dialogue with related countries and regions will be required.

Sweden

The Swedish government has set out an ambitious target to eliminate oil imports by 2020. Economic theory reports that innovation requires the co-existence of demand-side policies to complement supply-side measures (and not replace them) (OECD, 2011a). It has been observed that countries vary in the level of priority they give to demand-side policies (OECD, 2011c). The Swedish approach to using biofuels to reduce dependence on oil relies on using incentives to change the direction of fuel consumption, rather

than setting mandates or benchmarks that may be unattainable (Kroh, 2008). In fact, Sweden imports most of the ethanol that it uses.

Sweden is reported to have the largest bioethanol bus fleet in the world, with over 600 ethanol-operated buses in service. In 1994, the first three flex-fuel cars (powered by both ethanol and petrol) were imported. At the same time, the BioAlcohol Fuel Foundation (BAFF), founded in 1983 under the name of The Swedish Ethanol Development Foundation (SSEU), began lobbying other municipalities to invest in ethanol. At present, there are over 1700 E85[47] pumps found throughout Sweden.[48]

Sweden has produced a range of other consumer-oriented, demand-side policies supportive of biofuels to complement the supply side:

- A SEK 10 000 (over EUR 1 000) bonus to flex-fuel vehicle buyers (there are over 220 000 ethanol-fuelled vehicles in the country);
- Exemption from Stockholm congestion tax;
- Discounted insurance;
- Free parking spaces in most of the largest Swedish cities;
- Lower annual registration taxes;
- A 20% tax reduction for flex-fuel company cars; and
- Since 2005, Swedish petrol stations selling more than 3 million litres of fuel annually have been required to sell at least one type of biofuel.

On the supply side, Ford Sweden and Saab have become leaders in flex-fuel ethanol cars, and Volvo currently markets several ethanol-fuelled models, an example of supply- and demand-side policies operating simultaneously and producing spillovers.

The United States and RFS2

There is a large array of interacting policies supporting the production and consumption of biofuels in the United States. Until recently, ethanol and biodiesel, the two most widely used biofuels, received significant government support under federal law in the form of mandated fuel use, tax incentives, loan and grant programmes, and certain regulatory requirements. While the mandate remains, several tax incentives and other programmes have been terminated in recent years, several at the end of 2011, e.g. the *Small Ethanol Producer Credit*, the *Biodiesel Tax Credit*. There is also a shift in emphasis to large production facilities. Policies still in place under the DoE include:

- *Biorefinery Project Grants* of around USD 200 million per year for the biomass programme; and
- The *Loan Guarantee Programme*, authorising the DoE to provide loan guarantees for energy projects that reduce air pollutant and greenhouse gas emissions, including biofuels projects.

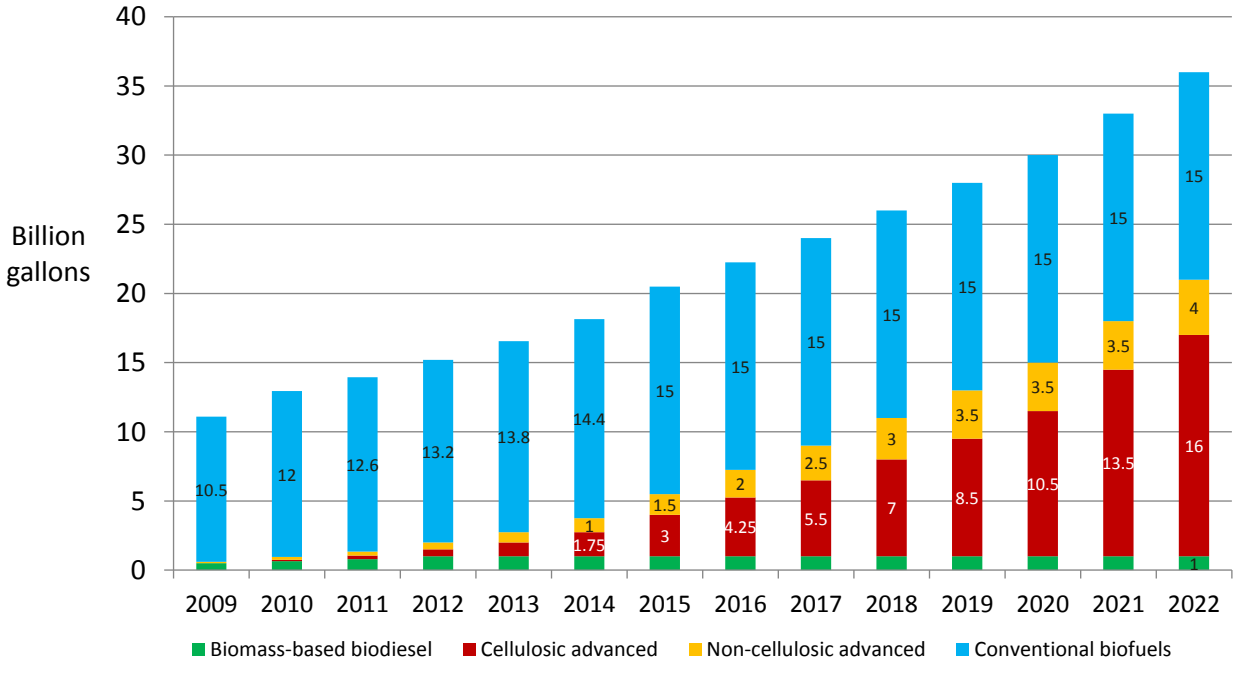
A summary of the array of policies, including information on current or expiry status, is given by Yacobucci (2012). In that report, the 22 programmes and provisions listed were established over the past three decades, and were administered by five separate agencies and departments: Environmental Protection Agency (EPA), United States Department of Agriculture (USDA), Department of Energy (DoE), Internal Revenue Service (IRS) and Customs and Border Protection. These programmes targeted a variety of beneficiaries across the value chain, including farmers and rural small businesses, biofuel producers, petroleum suppliers and fuel marketers.

It is worth exploring the United States Renewable Fuels Standard, RFS2 in some detail as it has been used by other countries as a model. It has also been credited with stimulating the bio-based industries in the United States, one source stating that it "gives comfort" to bio-based industry companies that there is strong support in place. Essentially, in aggregate, a given minimum amount (volume) of biofuel must be sold annually as part of the fuel supply, irrespective of the additional costs incurred.

In the United States, the *Energy Independence and Security Act* (EISA) (2007) and the *Farm Bill* (2008), which between them set biofuels volume mandates, created tax incentives, and provided funding for demonstration plants, are intended to pave the way for very large investments in research and infrastructure, and create further rural regeneration whilst working towards the aim of energy security. Out of the EISA came the latest iteration of the *Renewable Fuels Standard*, RFS2.

The RFS2 (Federal Register, 2010) lays out the strategy and targets for the United States till 2022, and therefore covers current and near-term biofuels development, but also has a provision for the inclusion of new technologies. The congressionally mandated RFS2 goal is to use at least 36 billion gallons of bio-based transportation fuels by 2022 (USDA, 2010). Fifteen billion gallons can come from conventional biofuel sources such as corn ethanol. Of the remaining 21 billion gallons of advanced biofuels needed to achieve the total 36 billion gallon goal, 16 billion gallons is required to come from advanced cellulosic biofuels (fuels made from cellulosic feedstocks that reduce greenhouse gas emissions by at least 60% relative to petrol). The contribution of biomass-based diesel to the 21 billion gallons goal can be no less than 1 billion gallons. An additional 4 billion gallons is to come from advanced biofuels (Figure 12). In total, the mandate will displace about 14% of the motor petrol demand in 2022.

Figure 11. RFS2 volume mandates to 2022



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

The EPA is responsible for enforcing the volume mandates, and it does so by first calculating the RFS blending percentages by dividing the volume of renewable fuels that are mandated by total expected US fuel use. For each year, the RFS percentage is used to determine the individual renewable volume

obligations (RVOs) of ‘‘obligated parties’’ (e.g. fuel refiners and blenders): the RVO for each obligated party is the product of the percentage standard and the firm’s annual fuel sales.

To ensure that such obligations are met, a Renewable Identification Number (RIN) system is used. RINs are unique identifiers assigned to ethanol batches at production that remain attached to these batches through the marketing chain. RINs are “separated” from ethanol batches only when they are blended with petrol, and can then be used by obligated parties to show that in fact they met their RVOs (Lapan and Moschino, 2012). Blenders can meet the RIN requirement by:

1. Buying a sufficient amount of ethanol to satisfy their RVOs or, alternatively;

2. Buying RINs from other obligated parties who are using more ethanol than they are mandated to use (and thus have an excess of RINs).

To reach this target, however, it is worth noting some caveats (OECD, 2011c):

- A rapid build-up in production capabilities is needed to meet the targets for cellulosic biofuels. Because commercial production of cellulosic ethanol and advanced biofuels is not meeting expectations, at present corn-based ethanol (up to the allowable limit) appears to be the only effective way to meet the aggregate biofuel mandate;

- The scope of the monetary investment for biorefineries is substantial. Second generation biofuels may come at 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;

- There are current infrastructure needs, in the form of blender pumps and rail and trucking infrastructure, even the construction of dedicated pipelines, which are at varying stages of being addressed by the market. Blender pump availability in the US mid-West is reasonable, but not so in some other states. In addition, 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 needs to be national in scope.

Besides its advocacy of volume mandates, another interesting policy aspect of the EISA of 2007 was that the Act also contained targets for the LCA of different types of biofuels. 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. To set the targets, GHG emissions were then compared to the lifecycle emissions of the petroleum baseline fuels that were displaced by the renewable fuels (N.B. EISA established 2005 as the base year). Setting targets represented a significant development because it was the first time that lifecycle emissions reduction had been specified as a legal requirement.

Volumetric Ethanol Excise Tax Credit (VEETC)

This was a policy to subsidise the production of ethanol. Administered by the IRS,[49] it was originally created by the *American Jobs Creation Act* of 2004. It had been the main source of financial support for biofuels. It was guaranteed for every domestic or imported gallon of ethanol blended with other fuels. It was awarded without quantity limits and independently of the price of petrol. Petrol suppliers who blend

ethanol with gasoline were eligible for a tax credit of 45 cents per gallon of ethanol (Yacobucci, 2012). It expired, along with the United States import tariff, at the end of 2011.[50]

The European Union

In the early years of bioenergy policy in the European Union, biofuels were supported mainly through *Directive 2003/30* (Official Journal of the European Union, 2003),[51] with the main objective being to trigger both domestic production and consumption in the member countries through measures of fiscal stimulus and incentives (Ninni, 2010). To help Member States comply with the target set by *Directive EC 2003/30*, the Commission introduced *Directive EC 2003/96 on Energy Taxation*,[52] which allowed Member States to exempt or reduce excise duties to compensate for the higher costs of producing biofuels (Global Subsidies Initiative, 2007). Since 2003, other documents, such as action plans and roadmaps, have been adopted by the Commission to complement and deepen the EU biofuel policy.

A major landmark in the European Union was the publication of the *Renewable Energy Directive* (RED) (Official Journal of the European Union, 2009). This directive 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. The European Union currently has a 5.75% liquid biofuels for road transport mandate in place, which is scheduled to increase to 10% by 2020. It also established sustainability criteria for biofuels.

However, in September 2013, the European Parliament voted for a change, in order that first-generation biofuels should not exceed 6% of the final energy consumption in transport by 2020, as opposed to the 10% target in existing legislation. Advanced biofuels, sourced from seaweed or certain types of waste, are expected to represent at least 2.5% of energy consumption in transport by 2020. These latest measures aim to reduce GHG emissions that result from the increasing turnover of agricultural land to biofuel production by including indirect land use change measures. Before becoming law, these proposals still have to be agreed with the 28 member states' governments.

There are seven key principles in RED specifying environmental criteria for liquid biofuels:

- Preservation of biodiverse lands;
- Consideration for the loss of carbon in soil;
- Protection of wetlands and many forests;
- Compliance with the European Commission (EC) requirements for agriculture;
- Encouragement of voluntary agreements on environmental and social issues;
- Monitoring of impacts on agriculture; and
- Support for wastes, non-food, and non-irrigated crops.

In the light of recent research addressing the risks of biofuels, the European Commission proposed further to favour the use of biofuels produced from wastes, residues, non-food cellulosic material, and lignocellulosic material over the use of first generation biofuels (Bringezu et al., 2009). However, the European Commission may now reduce the biofuels target from 10% to 5%, introduce ILUC into calculations on acceptable feedstocks, phase out the use of certain arable crops altogether, and provide

"multiple counting" benefits that may accelerate advanced biofuels adoption by providing huge incentives for their development.[53]

What works best for ethanol?

Not surprisingly, there is no universal correct answer. In the United States case of corn-derived ethanol, Lapan and Moschino (2012) suggest that the first-best policy from a welfare point of view would require three policy instruments: an import tax on oil, an export tax on corn and a carbon tax on emissions from fuel consumption. Taxes on carbon content for fuels, accompanied by certification, are better alternatives than other support mechanisms as they target CO_2 emissions directly (OECD/International Transport Forum, 2007).

However, this is hardly feasible in the United States. Despite the appeal of the simplicity of a carbon tax, it is very difficult to implement politically, and has proven so in other countries, e.g. France, where three successive governments have failed to implement carbon taxation (Sénit, 2012). Furthermore, the United States has international obligations through the World Trade Organisation (WTO) such that it cannot set arbitrary import tariffs. The United States constitution explicitly forbids the use of export taxes (Moschino, pers. comm., 2013).

Tax and excise measures

Political considerations may make it very difficult to consider increasing fuel tax, despite the economic merits of doing so. For example, in the United States fuel taxes are well below those of Europe, and therefore increases would perhaps be more palatable in the former.

Tax exemptions for biofuels clearly are not revenue-neutral. For example, VEETC cost the US taxpayers billions of dollars over its duration from 2004-2011.

Mandates

Lapan and Moschino (2012) have noted that an ethanol quantity mandate is equivalent to a combination of an ethanol production subsidy and a fuel (petrol) tax that is revenue-neutral. A limiting factor is the fact that, in most cases, mandates do not distinguish among biofuels according to their feedstock or production methods, despite wide differences in environmental costs and benefits (Lopolito et al., 2011), or even to ensure GHG emission reductions are delivered at all. They also may fail to provide incentives to contain financial costs. This implies that governments could end up supporting a fuel that is more expensive and has a higher negative environmental impact than its corresponding petroleum product (Global Subsidies Initiative, 2007).

Lapan and Moschino (2012) also found that neither ethanol subsidies nor ethanol mandates alone were able to achieve multiple policy goals, and that, in their framework, coupling either policy with a fuel tax would be beneficial.

No easy answer

From these arguments, it should be clear that there is no single 'correct' policy prescription for ethanol or, for that matter, for any biofuel. Several critical factors that influence the outcome include the individual country, the source of the feedstock, the production process, and indeed the criteria by which 'correctness' is measured. If climate change mitigation is the sole driving force for a particular country, then it could easily end up with an eco-efficient fuel that is more expensive than the fossil fuel options in the long term. Using less powerful, but politically more palatable measures, such as market readying

measures like filling station subsidies, would not necessarily be sufficient to stimulate the investments required to bring biofuels to the market competitively.

It is stressed that coherence between supply- and demand-side policies is an essential element of a successful strategy. If such policies are poorly aligned, problems such as those related to 'blend wall' are likely to occur. The 'blend wall' refers to the percentage of ethanol that companies are permitted to blend with petroleum-based fuel. If ethanol blend targets are set too low, supply dictated by policies setting high production targets can outstrip demand, leading to unwanted surpluses. Supply side policies promoting increased production of ethanol have to be coherent with the blend wall levels that dictate consumption levels and patterns. If they do not, additional policies facilitating increased ethanol consumption are needed, e.g. policies promoting the sale of FFVs that can run on ethanol blends, or policies designed to introduce more blend pumps at filling stations. Close integration and coordination of these policies, modelling of their interactions, and avoidance of lock-ins are other broad elements of a successful strategy.

POLICIES ASSOCIATED WITH BIOPLASTICS

This section is a short summary of the findings of a recent OECD report on bioplastics policies (OECD, 2013a). Overarching messages from that report, most of which are also relevant to the production of bio-based chemicals, are as follows:

- Bioplastics are suited to future manufacturing in a bioeconomy as their production will help to meet some major policy goals, such as climate change mitigation, job creation, landfill diversion, cleaning up the oceans, and rural regeneration (if the production plants are located in rural settings);

- The types and production volumes of bioplastics are increasing rapidly, although they currently account for a very small proportion of overall plastics production. There is also a shift towards the bio-based thermoplastics that have oil-derived equivalents. These offer GHG emissions savings compared to the oil-derived counterparts, but are not biodegradable. However, as they are identical molecules to the thermoplastics that dominate the market, they are able to enter established recycling infrastructures;

- Globally there are very few policies dedicated to supporting the growth of the bioplastics industry or to removing barriers to their production. When compared to support for biofuels, the policy regime is almost negligible;

- There is an emerging competition for biomass in the separate sub-sectors of bioenergy (especially bioelectricity), biofuels and biomaterials (generally bio-based chemicals and plastics);

- To realise the concept of the integrated biorefinery, it may be necessary to make bio-based chemicals and plastics at the same facilities as biofuels, not for any consideration of convenience, but simply to keep high-volume, low-margins fuels production viable economically. This margins trap is apparent in the oil refining industry, where a global trend towards upstream and downstream integration is being observed;

- Support measures for bioenergy and biofuels could be more effective in the context of a balanced bioeconomy if they formed an integrated policy for the bio-based production industry.

It is worth explaining further the biomass competition that is emerging. The massive use of wood chips to produce electricity by burning in dedicated power plants or for co-generation in coal-fired power plants is causing the price of wood chips to rise. If subsidised biomass is not available for bio-based chemicals and plastics production, then it will become increasingly difficult for bioplastics to compete on price with oil-derived plastics. The trend towards a lowering of the price differential between the two could be nullified.

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 relative 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 are using public procurement to stimulate market development; and
- There is a growing interest in the development of comprehensive bioeconomy strategies in many countries around the world, with scope for targeted bioplastics initiatives within 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 relative disadvantage, deserves 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.

Table 10 (from Hermann, 2011) summarises the impact of the major policies that have been used to support bioplastics.

Table 10. Policy initiatives affecting the market penetration of biomaterials*

Initiative	Target material	Policy goal	Country	Year	Impact to date
Federal Biobased Products Preferred Procurement Program (FB4P)	Bio-based materials	Support bio-based	US	Since 2002	+
Green Public Procurement (GPP)	Sustainable products		NL	Since 2003	0[a]
Banned products	All plastic bags	Reduce waste and littering	Several		0[a]
Mandate	Biodegradable bin liners	Support biomaterials	IT	Since 2008	+
Mandate	Bio-based plastic bags	Reduce waste and littering	ES	Starts 2015	0[b]
Mandate	Biodegradable carrier bags	Reduce waste and littering	IT	Since 2011	+
Emissions Trading System (ETS)	CO_2 emissions	Tackling climate change	EU	2008-2012	0[a]
Subsidies	Bio-based insulation	Increase market penetration	DE	2003-2007	+
Subsidies	Bio-based lubricants	Increase market penetration	DE	2001-2008	+
Tax	Packaging materials	Reduce packaging	NL	2008	0[b]
Tax	Non-degradable single-use materials	Reduce waste and littering	BE	Since 2007	0[b]
Tax	All plastic bags	Reduce waste and littering	Several		0[a]
FB4P labelling	Bio-based materials	Increase awareness	US	Since 2010	0[c]
Eco-labelling	Bio-based materials	Increase awareness	EU	Since 2005	0[c]
Carbon labelling	All materials	Reduce environmental footprint	Several		0[c]
Campaigns	Bio-based economy	Increase awareness	UK	Since 2003	0[c]

* *Table Notes*: a) Not specifically targeting biomaterials
b) Only recently implemented
c) Incentive is not strong enough

Source: Hermann et al. (2011)

As the main barrier to market penetration of bioplastics is price in comparison to oil-based plastics, an update on these costs is worthy of inclusion here (Table 11).

Table 11. Updated prices of bioplastics

Product	Company	Location	Capacity (tonnes)	Price (EUR per kg)
PLA	NatureWorks	United States	140 000	1.5 - 2.0
PLA	Hisun	China	5 000	2.1
PHAs	Metabolix	United States	300/50 000	4.3 - 4.6
PHBV	Tianan	China	2 000	4.1 - 4.3
Mater-Bi	Novamont	EU	75 000	3.4 - 5.1
Cereplast	Cereplast	United States	25 000	2.6 - 3.4
HDPE/LDPE/PP	Braskem	Brazil	200 000	1.3 - 1.7
Other	DuPont Plantic Innovia Arkema, others	Global	2 000	2.5 - 6.9

Source: Assembled from multiple sources. Elipso 09/2012: Pellet prices (EUR per kg) - PE = 1.58; PP = 1.54; PET = 1.73.

Some intuitive reasons why the bio-based industry is split in policy terms can be identified. Given that energy security is a major policy goal for many countries, it is understandable that bioenergy and biofuels take precedence. In turn, when major public policies for bioenergy and biofuels are implemented, investors find the idea of capturing a tiny percentage of the lucrative fuels market much more attractive than trying to capture a larger percentage of the chemicals or plastics market, where production volumes are much lower and regulation tighter. For all the reasons outlined above, however, the prospects for a sustainable bioeconomy are much higher if an integrated policy regime across the bio-based industries can be realised.

THE POTENTIAL FOR BIO-BASED CHEMICALS TO REPLACE FOSSIL-BASED CHEMICALS

How much substitution of fossil-derived chemicals and plastics is possible using bio-based equivalents or new molecules? Jay Keasling, a leader in the field, believes that "*through synthetic biology, all petroleum-based products can be produced from sugar-based microbes resulting in cleaner processes and slowing global warming*."[54] There is mounting evidence, especially from efforts in metabolic engineering and synthetic biology, that even completely unnatural compounds can be manufactured using microbial cells. However, what is achievable in the research laboratory may never see commercial exploitation. Both economics and technical difficulties with production strains may restrict many promising projects to the laboratory.

The list of potential chemicals that could be produced via a biotechnology route is impracticably large to define at this early stage in the development of the bio-based economy. However, an idea of the diversity can be gained from EuropaBio (2008). This source lists bulk commodity, fine, specialty, and platform chemicals and a growing range of bio-based plastics, especially the bulk-production thermoplastics.

A US Department of Energy (DoE) report from 2004 identified twelve building block chemicals that can be produced from sugars via biological or chemical conversions (Table 12). Building block chemicals are considered to be molecules with multiple functional groups that possess the potential to be transformed into new families of useful molecules. They can therefore be termed platform chemicals.

Table 12. The US DoE top value-added chemicals from biomass feedstocks

Chemicals
1,4 diacids (esp. succinic, fumaric, malic)
3-hydroxypropionic acid
Levulinic acid
Glutamic acid/MSG
Sorbitol
Xylitol/arabinitol
2,5 furan dicarboxylic acid
Aspartic acid
Glucaric acid
Itaconic acid
3-hydroxybutyrolactone
Glycerol

Source: adapted from US DoE (2004)

Since that time, however, many bio-based production breakthroughs have been seen with other chemicals. It is now evident that, in recent years, the bio-based chemicals subsector, although small, has grown much faster than the petrochemicals sector, and is predicted to continue to do so (Philp et al., 2013).

Achieving a market position with bio-based platform chemicals would improve the future prospects for bio-based production. Table 13 shows platform chemicals from a later publication that could potentially be made using cellulosic feedstocks.

Table 13. Thirteen 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-ethanediol, 1,2-propanediol, 1,3-propanediol	Fermentation or via chemocatalytical processes
Polyols	Sorbitol, xylitol	Hydrogenation of cellulose and hemicelluloses respectively
Dicarboxylic acids	Acetic, lactic, succinic, 3-hydroxypropanoic	Fermentation

Table Note: Since then, the laboratory biosynthesis of 1,4-butanediol has also been described, a significant achievement as it is an entirely synthetic compound without natural precedent.

Source: Sheldon (2011)

The global chemical market was estimated at USD 1.2 trillion in 2005. Commodity chemicals and polymers contributed 60% to the total; followed by specialty chemicals, 30%; and fine chemicals, 10%. The global chemical industry is projected to grow 3-6% per year through to 2025. Bio-based chemicals are expected to grow to at least 22% by 2025. Excluding pharmaceuticals, the global chemical industry is expected to grow to over USD 2 trillion per year by 2025, with bio-based products replacing existing products and providing new revenue sources amounting to more than USD 500 billion per year (USDA, 2008).

A challenge for the bio-based industry is to convert unconventional feedstocks into the basic building blocks for advanced chemicals. However, these early-stage conversions produce the simplest and cheapest commodity chemicals, and it is difficult, if not impossible, for most small bio-based companies to make a profit on them as the petrochemical equivalents have had decades to achieve economies of scale. Intermediate and advanced specialty chemicals are more lucrative, but by far the most common way to create bio-based versions is to have the relatively unprofitable building blocks (Milken Institute, 2013).

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, by no means all of which are biodegradable or compostable.

The most significant development has been the arrival of the 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. Bio-PE and bio-PP are not directly fermented; they are produced chemically from monomers that 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 GHG emissions savings. It has been predicted that the global trend in bioplastics production will change significantly to be dominated by durable bio-based thermoplastics (OECD, 2013a).

The major contributions to this change would be largely as a result of increased production capacity for bio-PE, bio-PP, bio-PET and, potentially, bio-PVC. However, a recent update, from the industry

organisation European Bioplastics[55] 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-Institüt predicted that by 2020 bioplastics production could rise to 12 million tonnes, principally due to drop-in polymers, particularly bio-PET.[56]

How far this substitution of fossil-derived plastics can go 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 USDA has estimated the upper limit for substitution to be 33% (OECD, 2011c).

Bio-based succinic acid: the argument for bio-based in a nutshell

Succinic acid is one of those top twelve chemicals identified by the US DoE as candidates for bio-based mass production. The market for only four of the major succinic acid derivatives is estimated to be USD 4.8 billion per year (Lee et al., 2011). It is produced efficiently by petrochemical routes (though this involves the oxidation of butane or benzene), but it can also be produced via biological routes. One advantage is that succinate fermentation fixes CO_2, thereby consuming it, unlike ethanol fermentation, which produces it. Moreover, waste materials can be used to produce bio-based succinic acid. For example, recently the feasibility of utilising waste bread as a feedstock was demonstrated (Leung et al., 2012). UK Department for Environment, Food and Rural Affairs (Defra) figures show that 32% of bread purchased by UK households is dumped rather than eaten.[57]

Bio-based production is therefore potentially much more eco-friendly compared to the petrochemical process. The natural fermentative production is, however, inefficient and work is underway to improve yields using techniques of metabolic engineering (e.g. Beauprez et al., 2010).

Examples spanning the value chain

Rather than exhaustively listing bio-based chemicals, some examples are given here. A more comprehensive review is given by IEA Bioenergy Task 42 Biorefinery (2012).

Ethylene

Petrochemically-derived ethylene is the largest production organic chemical globally (Chemical and Engineering News, 2006), with demand in recent years continuously increasing (Table 14), and with production in over fifty countries. The range of uses described below demonstrates the strategic nature of ethylene in modern consumer society.

Table 14. Ethylene production globally by year

Year	Global production (million tonnes)
2005	107
2006	109
2010	138
2011	141

Sources: Ceresana (2010); True (2012).

The capacity is expected to increase to 165 million tonnes in 2015, with demand reaching 151 million tonnes.[58] Projections suggest that bioethylene could meet between 40-125% of the global demand by 2035, depending on scenarios and taking into account co-products. However, several industrial sectors (e.g. transportation fuels, power generation and the chemical industry) might compete for the availability of biomass feedstock.

Regarding bioethylene, the current production capacity is about 375 kt (kilotonnes) per year, of which 200 kt/y is used for producing polymers (bio-PE) and the remainder for producing bio-based ethylene glycol (EG).

Uses of ethylene

Ethylene is the raw material used in the manufacture of polymers such as polyethylene (PE) (about 60% of global demand), polyethylene terephthalate (PET), polyvinyl chloride (PVC) and polystyrene (PS) as well as fibres and other organic chemicals. These products are used in a wide variety of industrial and consumer markets such as the packaging, transportation, electrical/electronic, textile and construction industries as well as consumer chemicals, coatings and adhesives.

The next largest consumer of ethylene is ethylene oxide (EO) which is primarily used to make ethylene glycol. Most monoethylene glycol (MEG) is used to make polyester fibres for textile applications, PET resins for bottles and polyester film. MEG is also used in antifreeze applications. Other EO derivatives include ethoxylates (for use in shampoo, kitchen cleaners), glycol ethers (solvents, fuels) and ethanolamines (e.g. surfactants, personal care products).

Chemical route to ethylene

Ethylene is produced by heating either natural gas, especially its ethane and propane components, or petroleum to 800–900 °C, giving a mixture of gases from which the ethylene is separated. It is highly energy-intensive, requiring various stages of cracking, gas drying and cryogenic treatment. It requires high-pressure steam at 1200 psig, but energy recovered from gas cracking is used for this. This steam is in turn used to drive the turbines for compressing cracked gas, the propylene refrigeration compressor, and the ethylene refrigeration compressor. An ethylene plant, once running, does not need to import steam to drive its steam turbines. Methane recovery is critical to the economical operation of an ethylene plant.

Biological route to ethylene

Ethanol fermentation and catalytic dehydration (ethanol-to-ethylene, ETE process)

Bioethanol can be produced by the fermentation of a variety of plant biomass sources, which is then converted to bioethylene via catalytic dehydration. In addition to hydrolysis and fermentation (i.e. the biochemical route), lignocellulosic biomass can be converted into ethanol by thermo-chemical processes (Foust et al., 2009). These involve feedstock gasification (i.e. production of syngas) and subsequent conversion into ethanol by fermentation, followed by catalytic conversion by an alumina or silica-alumina catalyst to ethylene.

While the ethanol-to-ethylene (ETE) process is relatively simple, it has scarcely been used for several decades, and technological improvements can be expected to improve performance further. There are various reactor types that can be used for the catalytic stage (see Morschbacker, 2009), all of which operate at elevated temperatures. The process requires low investment per ton of product, even at small scales.

Environmental performance

The environmental performance of bioethylene depends largely on the regional conditions for the production of bioethanol. In general, bioethylene can significantly reduce the environmental impact of the chemical industry. Based on recent estimates, bioethylene can reduce GHG emissions by up to 40% (cradle-to-gate) and save fossil energy by up to 60% compared to petrochemical ethylene (IEA-ETSAP and IRENA Technology Brief I13, 2013). Bioethylene from corn and lignocellulose save less energy and GHG emissions than this because related processes do not export electricity. However, lignocellulosic bioethylene would be much less demanding in terms of land use.

Price difference between chemical and bio-based ethylene

Ethylene production costs are mostly determined by underlying feedstock prices that derive from either natural gas (ethane, butane and propane) or crude oil (naphtha and gas oil). The cost of petrochemical ethylene is (2013 prices) USD 600-1 300 per tonne, depending on the region with a global average of USD 1 100 per tonne. By comparison, the current production cost of bioethylene is between 1.1-2.3 times higher than the global average petrochemical ethylene, but lignocellulosic bioethylene is expected to reduce the gap in the near future.

In Brazil, bioethylene production is already economically competitive due to the ample availability of cheap sugar cane feedstock, extensive experience in ethanol production and increasing oil prices. Bioethylene production costs are very low in Brazil and India (around USD 1 200 per tonne). Chinese production based on sweet sorghum is estimated at about USD 1 700 per tonne. Higher costs are reported in the United States (from corn) and in the European Union (from sugar beets) at about USD 2 000 per tonne and USD 2 600 per tonne, respectively. At present, the cost of lignocellulose-based production is estimated at USD 1 900-2 000 per tonne in the United States.

Policy implications

Biomass availability and the price gap with petrochemical ethylene are the two most important determinants for the future of bioethylene, although bioethylene can also contribute to energy security in oil-importing countries. While promoting the optimal use of biomass, including cascading use in various sectors of the economy, policy measures can support the deployment of bioethylene production capacity by supporting the use of bio-based materials via incentives, carbon tax schemes, eco-labelling or information campaigns (Hermann et al., 2011), and removing import tariffs on bioethanol (Vermie and Akkerhuis, 2009).

Future fossil fuel prices will remain a key factor in determining to what extent bioethylene can substitute for petrochemical ethylene. Policy measures may also be made to take into account life cycle emissions of products, not only the chemical sector on-site emissions occurring during the production process. Various scenarios envisage future crude oil prices ranging from USD 90-135 and above. This difference could have a significant impact on the economic attractiveness of bioethanol and bioethylene production. Removing subsidies for consumption of fossil fuels would help close the price gap between petrochemical and bio-based products.

Abundant biomass resource is the key to scaling-up production and reducing bioethanol costs, and commercial projects based on lignocellulosic biomass are currently supported by policy incentives and government loans in many countries. The production of bioethylene is one bio-based chemical process that could benefit from the proliferation of biofuels policies, but only if there are sufficient incentives to stimulate the conversion of bioethanol to bioethylene. Bulk diversion of biomass to biofuels production

could strangle the carbon supply for chemicals production, and alternative policy choices may be needed to determine the optimum distribution of biomass feedstock to various branches of the economy.

Credit should be granted to entire life cycle CO_2 benefits. This would also mean that carbon tax systems would more effectively motivate companies to produce bio-based products because they would offer larger CO_2 emission reductions.

1,3-Propanediol (PDO)

1,3-Propanediol is a platform chemical in its own right. DuPont and Tate & Lyle produce 100% bio-based 1,3-propanediol in a 50/50 joint venture formed in 2004. Globally, the 1,3-propanediol market will grow from an estimated USD 157 million in 2012 to USD 560 million in 2019 with a compound annual growth rate of 19.9% during the period 2012 to 2019. At present, the market is dominated by DuPont Tate & Lyle (United States) which is the only bulk producer of 1,3-PDO. In terms of geographical markets, the Americas region is the largest market followed by Asia-Pacific and then Europe, Middle East & Africa (EMEA).[59]

Uses of 1, 3-Propanediol

1,3-PDO has appealing properties for many synthetic reactions such as polycondensation, and for uses in solvents, adhesives, resins, detergents and cosmetics. It is especially well known as a monomer for the synthesis of polytrimethylene terephthalate (PTT), a polyester with excellent properties for fibres, textiles, carpets and coatings (Zeng & Sabra, 2011).

Chemical route to 1, 3-Propanediol

1,3-Propanediol may be chemically synthesised by the hydration of acrolein, or by the hydroformylation of ethylene oxide to 3-hydroxypropionaldehyde. The aldehyde is hydrogenated to give 1,3-propanediol. Acrolein is extremely toxic and has been routinely used as a biocide in the oil industry and as a contact herbicide. It is carcinogenic and mutagenic, and potentially teratogenic.

Ethylene oxide has been used as a sterilising gas, being highly toxic to microorganisms. It is a suspected human carcinogen. Exposure may cause toxicity to the human reproductive system including spontaneous abortions. Chromosomal aberrations have been detected in ethylene oxide exposed workers.

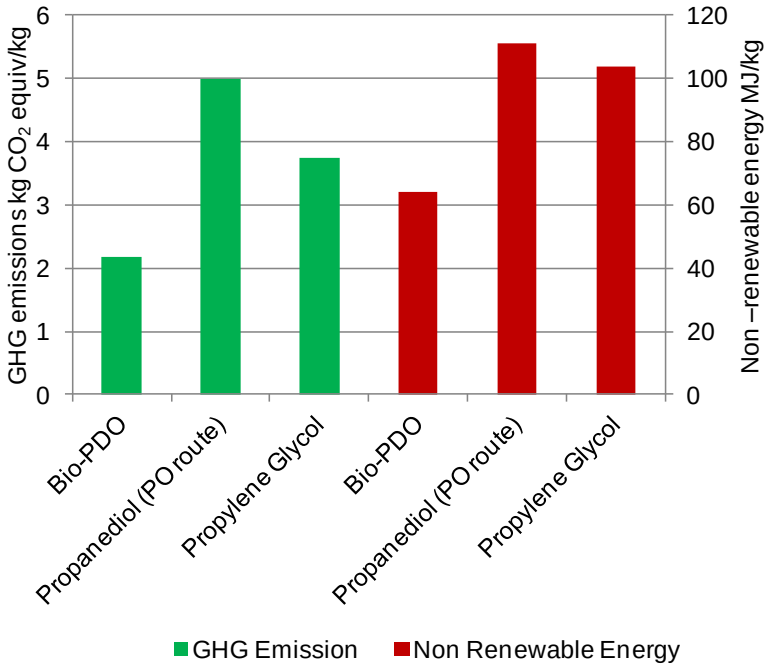
Biological route to 1, 3-Propanediol

The natural substrate for microbial production of 1,3-PDO is glycerol. Glycerol is dehydrated to 3-hydroxypropionaldehyde (3-HPA) by glycerol dehydratase. Since 50% of the entire cost of microbial production of 1,3-PDO is due to the price of raw materials, raw glycerol from biodiesel production processes may be an interesting renewable carbon source for microorganisms that produce 1,3-PDO (González-Pajuelo et al., 2004). Reviews from Nakamura and Whited (2003) and (Kurian (2005) also detail the microbial production of 1,3-propanediol.

Environmental performance

The DuPont website claims that, in cradle-to-gate analysis, the production of Bio-PDO™ consumes up to 40% less energy and reduces greenhouse gas emissions by more than 40% versus petroleum-based 1,3-PDO[60] (Figure 13).

Figure 12. Environmental performance of 1,3-Propanediol



Source: Adapted from www2.dupont.com/Bio-based_Propanediol/en_CN/

It is worth mentioning the need to shorten the innovation cycle in biobased production. This is often off-putting for potential investors, especially venture capitalists. It took DuPont and Genencor approximately 15 years and 575 person years to develop and produce 1,3-PDO (Hodgman & Jewett, 2012).

1,4-Butanediol (BDO)

World production of 1,4-butanediol was about one million tonnes in 2005. The global BDO market was 1.72 million tonnes in 2011 and is estimated to reach 2.54 million tonnes by 2017, growing at a CAGR of 5.5% from 2012 to 2017.[61]

Uses of 1,4-Butanediol

1,4-Butanediol is used industrially as a solvent and in the manufacture of some types of plastics, elastic fibres and polyurethanes, and can be dehydrated to the important solvent tetrahydrofuran, which is used in the production of fibres such as Spandex. Globally it is used to make over 2.5 million tonnes of plastics, polyesters and fibres annually.

Chemical route to 1,4-Butanediol

BDO currently is manufactured entirely from petroleum-based feedstocks such as acetylene, butane, propylene and butadiene (Kroschwitz and Howe-Grant, 1993). In its industrial synthesis, acetylene reacts with two equivalents of formaldehyde to form 1,4-butynediol, also known as but-2-yne-1,4-diol (WHO, 2012).

Biological route to 1,4-Butanediol

Two factors make a biological route even more challenging than for some other chemicals:

1. The chemically reduced nature of BDO relative to carbohydrates (in common with many other commodity chemicals);
2. BDO is not a compound produced naturally in any known organism.

Therefore, a bio-based version of BDO requires the techniques of metabolic engineering and synthetic biology. Recent work by Yim et al. (2011) described an experimental route to BDO in a metabolically engineered *Escherichia coli*. At the time of publication, it was recognised that commercialisation will require another three- to five-fold increase in yield and, to this end, measures have been taken to raise yield rates at key steps along the pathway, to remove metabolic inefficiencies and to reduce by-products substantially. Genomatica will commercialise this process in Italy in 2014. The total project time to commercialisation is only five years in this case, a substantial improvement in the innovation cycle of bio-based production through metabolic engineering.

Polylactic Acid (PLA)

Amongst biomaterials used in the medical field, polylactic acid (PLA) has received significant attention. Apart from its biodegradability, other important properties include its transparency, its excellent film-forming properties, and its good thermal, mechanical and processing properties. It can also be used in packaging (Cava et al., 2006).

Uses of PLA

Polylactic acid, first synthesised at least 50 years ago, has finally arrived as an alternative to PET, HIPS, PVC, and cellulosics in some high-clarity packaging roles. PLA is being used in confectionery wrapping, optically enhanced films, and shrink labels. It is being used in vehicle interiors, replacing plastics with greater GHG emissions.

Chemical route to PLA

Two main synthetic methods are used to obtain PLA: direct polycondensation (including solution polycondensation and melt polycondensation), and ring-opening polymerisation (ROP) (Table 15).

Biological route to PLA

The majority of commercially produced lactic acid is made by the bacterial fermentation of carbohydrates, using homo-lactic organisms such as various optimised or modified strains of the genus *Lactobacillus*, which exclusively form lactic acid (Garlotta, 2002).

Environmental performance

PLA production consumes 25-55% less fossil energy than petroleum-based polymers. Cargill Dow has targeted a reduction in fossil energy consumption by more than 90% as compared to any of the petroleum-based polymers for the near future, which will also lead to significant reductions in air and water pollutant emissions (Xiao et al., 2012).

Table 15. Comparison of PLA synthesis methods

Synthesis methods	Advantages	Disadvantages
Solution polycondensation	One-step, economical and easy to control	Impurities, side reactions, pollution, low molecular weight PLA
Melt polycondensation		High reaction temperature, sensitivity to reaction conditions, low molecular weight PLA
Ring-opening polymerisation	High molecular weight PLA	Requires strict purity of the lactide monomer, related high cost
New solutions (new catalysts, Polymerization conditions, etc.)	Efficient, non-toxic, no pollution , high molecular weight PLA, etc.	Under development
Biosynthesis	One-step, efficient, non-toxic, no pollution, low cost	Under development

Polyhydroxyalkanoates (PHA)

Polyhydroxyalkanoates (PHAs) are diverse polyesters (Table 16) synthesised by numerous bacteria as intracellular carbon and energy storage compounds and accumulated as granules in the cytoplasm of cells (Lee, 1995).These are true biodegradable plastics formed directly by fermentation. Among the candidates for biodegradable plastics, PHAs have been drawing much attention because of their similar material properties to conventional plastics and complete biodegradability.

Table 16. Commercially available PHA polymers

Trade name	Structure	Supplier	Origin	Website
Biopol	poly(3-hydroxybutyrate-co-3-hydroxyvalerate)	Metabolix	USA	www.metabolix.com
Nodax	poly(3-hydroxybutyrate-co-3-hydroxyalkonate)	Kaneka/P&G	Japan	www.nodax.com
Biogreen	poly(3-hydroxybutyrate)	Mitsubishi	Japan	www.mgc.co.jp
Biomer	poly(3-hydroxybutyrate)	Biomer	Germany	www.niomer.de

Source: OECD research

Uses of PHA

PHAs can be used in a wide range of short-term packaging applications. PHAs are currently used to produce plastic films for bags, containers and paper coatings, in disposable articles (personal care products, surgery clothes), upholstery and other diverse packaging applications.

Biological synthesis of PHA

Three different routes to biotechnological production of PHA are known (Bioplastics Magazine, 2011):

1. Bacterial fermentation;

2. Synthesis in genetically modified plants; and

3. Enzymatic catalysts in cell-free systems.

PHA production by bacterial fermentation is the only method available at industrial scale at present.

Environmental performance of PHA

The property that distinguishes PHAs from petroleum-based plastics is their biodegradability. The rate of biodegradation of PHA materials depends on many factors, notably those related to the environment (temperature, moisture level, pH, and nutrient supply) and those related to the PHA materials themselves (e.g. composition, additives, surface area).[62] PHA degrades upon exposure to soil, compost, or marine sediment (Reddy et al., 2003).

Price difference between chemical and bio-based PHA

Commercial applications and wide use of PHA is hampered due to its price. The cost of PHA using the natural producer *Cupriavidus necator* (formerly *Alcaligenes eutrophus*) is USD 16 per kg, which is many times more expensive than polypropylene. With recombinant *E. coli* as a producer of PHA, the price can be reduced to USD 4 per kg, which is close to other biodegradable plastic materials such as PLA and aliphatic polyesters.

Astaxanthin

Astaxanthin is an interesting example of a very high value compound that is a potential target for bio-based production. Astaxanthin is a carotenoid found in microalgae, yeast, salmon, trout, krill, shrimp, crayfish, crustaceans, and the feathers of some birds. It provides the red colour of salmon meat and the red colour of cooked shellfish. It is employed widely as a component of the feed used by fisheries and poultry farms (Aflalo et al., 2007), but it adds significantly to costs (synthetic astaxanthin costs approximately USD 2000 per kilogramme to produce (Guerin et al., 2003)). Currently carotenoids produced by chemical synthesis dominate the global carotenoids market (about USD 1 billion annually) because biological sources are still limited and extremely expensive. In nature, carotenoids are abundant in number, but present in trace amounts. This greatly complicates commercialisation efforts from natural sources (one source[63] quotes a price of USD 7000 per kg for natural astaxanthin).

The lack of fermentation production systems, combined with shortfalls of chemical synthesis, has led to metabolic engineering research to improve natural production yields. Scaife et al. (2009) described the overexpression of individual β-carotene ketolase and β-carotene hydroxylase genes, within an *E. coli* host, enabling a 23.5-fold improvement in total carotenoid yield over the parental strain, with more than 90% of the yield being astaxanthin.

More recently, Huang et al. (2013) described the engineering of tomato for high yield production of astaxanthin by expressing a specific pair of algal *BKT* and *BHY* genes that were identified as the best combination for astaxanthin production from β-carotene. Compared to the microalga *Haematococcus pluvialis*, which needs a well-controlled environment (e.g. growth in an enclosed photobioreactor) for pure culture, tomato is a food crop cultivated cost-efficiently worldwide with very high yields. At some future date, astaxanthin production in tomatoes might be an effective commercial production route for the natural compound.

CONCLUDING REMARKS

There are as many hurdles to bio-based materials production as there are opportunities to be grasped. For many governments, bio-based materials production still appears to be a novel, niche activity compared to more immediate and pressing political priorities. One purpose of this paper, however, is to outline critical policy choices and highlight the role that the bio-based production of materials, energy and fuels could play in creating new jobs, enabling green growth and addressing important grand challenges. These include energy security (where the impacts of policy can typically be seen within a political cycle of five years) and climate change (where immediate policy actions are an imperative even though it may take longer for their impacts to be observed).

One striking feature of the current situation is that there is a large body of literature accumulating on the concept of the integrated biorefinery. Another is that this concept is being discussed at a political level. Enshrined in the concept is the notion that multiple feedstocks can be used within a single facility to produce fuels, chemicals, plastics, heat and electricity. To date, the concept is better developed than the policy actions that could support it.

Many policy avenues that do not necessarily entail huge public cost could be explored to rectify this situation. One option would be to support the production of bio-based materials by deploying the same policy mechanisms that are used to support the production of bioenergy and, in particular, biofuels. Not all bioenergy and biofuels policies are amenable to this (e.g. feed-in tariffs), but others are. Ensuring equivalence between the support measures used for biofuels and bioenergy and those used for bio-based materials would level the playing field and increase the prospects of success for integrated biorefineries. Utilising the same policy frameworks would also limit additional administrative costs to marginal increases.

Policy action is only likely, however, if governments recognise the full potential of the bio-based production of chemicals and plastics. If bio-based chemical production, for example, remains limited to a small number of niche chemicals and a few platforms, governments might reasonably conclude that policy support is not warranted. On this front, however, there are encouraging signs. The recent laboratory production via a biotechnological route of a totally unnatural but industrially important chemical was reported. This is a significant breakthrough, as it will encourage other scientists to work on similar chemicals, which are exceedingly common in everyday products. The hope and expectation is that this will then lead to the synthesis of a large range of industrially important chemicals via biotechnological routes at industrial as well as laboratory scale, paving the way for biochemicals to challenge the supremacy of petrochemicals and underpinning the emergence of bio-based production as a dominant manufacturing paradigm.

NOTES

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ANNEX 1 RECENT SUGGESTIONS FOR BIO-BASED MATERIALS POLICY FROM THE EUROPEAN UNION AND THE UNITED STATES

These two examples of policy suggestions are both themed around opening up policy support in place for biofuels and/or bioenergy to bio-based materials. Given all potential options, this strategy is probably the quickest and least expensive to the public.

Some suggested policy measures from the European Union (from Carus et al., 2011)

Quotas, bans, public procurement and emission trading

- Indicative/mandatory targets and quotas for bio-based products by 2020.
- Open the European Union biofuel quota to bio-based products (as the target for the share of renewables in transport was opened for electric cars in 2008).
- Bans on critical fossil based chemicals, plastics and additives which can easily be substituted by less hazardous bio-based chemistry.
- Implementation of strong green public procurement programmes for bio-based products
- Ensure that bio-based products are incentivised in climate change/carbon legislation including carbon trading and credits (ETS – Emission Trading System).
- Open regulations, programmes, and subsidy systems supporting bioenergy and biofuels to bio-based chemicals and materials.

Taxes

- Support taxation of non-renewable carbon as input for the chemical industry; at present, a paradox system is implemented with double disadvantages for industrial material use of biomass: In the energy sector there are high taxes on fossil carbon sources and high support for bioenergy – in the material sector there are no taxes on fossil carbon and no support for biomaterials.
- Allow member states to reduce taxes for sustainable bio-based product categories (like the European Union-framework for member states in the energy taxation directive).
- Comprehensive establishment of CO_2 taxes including all bio-based sectors (energy and material).

Agriculture

- The Common Agriculture Policy (CAP) reform could be an option for re-balancing the support of bioenergy versus industrial material use.
- Replace the former CAP "production refund" by an alternative incentive to support the use of renewable raw materials for industrial uses.
- CAP should become an interface between agriculture and the bio-based economy, including bio-based chemicals and materials; this is a huge chance for the farmers.
- Integrate in the new CAP specific financial incentives for farmers to improve the logistical capabilities to collect biomass by-products and residues from agriculture and forestry.

- All programs in structural funds and rural development that are being used to support and implement bioenergy and biofuels should be opened to bio-based products – all criteria for funding should be handled equally.

Additional instruments

- Use regulations like the European Union End-of-Life Vehicle Directive for supporting bio-based products through waste legislations (consider bio-based materials as recycled regardless of how they are recovered) to make bio-based products attractive for the industry.
- Ensure that bio-based products can enter all waste collection and recovery systems, including composting, recycling and energy recovery. Bio-based plastics certified compostable according to EN 13432 should gain unhindered access to bio waste collection.

Suggested general policies and measures to promote wider use of renewable raw materials (RRM)

Potential policy measures	**Objective**
Medium and long term R&D and demonstration	Increase applications and economic performance, increase range of additives to improve engineering parameters
Standardisation	Harmonise standards (*e.g.* composting)
Public procurement	Enable commercialisation, create economies of scale
Limited fiscal and monetary support (*e.g.* reduced VAT rate)	Enable commercialisation, create economies of scale
Include in climate and product policy	CO_2 credits for manufacturers/users
Adaptation of waste legislation and waste management	Improve infrastructure for separate collection (financial incentives for consumers)
Inclusion in agricultural policy	Secure stable supply of biomass feedstocks
Public awareness	Widen understanding of benefits

Note: RRM refers to renewable raw materials, and RRM is a synonym for bio-based materials. Apart from bio-based polymers the group of RRMs comprises bio-based lubricants, solvents and surfactants.

Source: Modified from Crank *et al.*, 2005.

Some suggested policy measures from the United States (based on the Industrial Biotechnology Industry Report, 2010)

Provide product parity and early-stage support in biorenewables tax policy via the following steps:

- Enact a production tax credit (PTC) for bio-based products;
- Open the 48C advanced energy manufacturing credit to renewable chemical and bio-based product biorefineries;
- Provide robust early-stage R&D credits to drive development of specialty biochemicals.

Increase funding through grants and other programmes for non-fuel bio-based products via the following steps:

- Open existing loan guarantee programmes to bio-based product projects;
- Ensure that existing and future grant programmes support bio-based products;
- Establish grants and loans to help struggling biorefineries add high-value chemical production.

Ensure that bio-based products are incentivised in climate change/carbon legislation via the following steps:

- Include production of bio-based products in the list of eligible offset project types to drive investment in critical low-carbon bio-based products.

Ensure timely implementation and eligibility of renewable chemical intermediates in USDA Biopreferred voluntary labelling and procurement programmes.