Chapter 9.

Enabling bio-based materials policy

In recent years, the absence of policy support for bio-based chemicals and materials production in the face of huge support for both biofuels and bioenergy has been a matter of contention. This lopsided emphasis has serious consequences for integrated biorefineries of the future. It systematically allocates (subsidised) biomass to fuels and energy applications; as a result, opportunities for high value-added and greater job creation could be missed. If lessons from petro-fining are any indication, lack of support for bio-based chemicals and materials production may completely throw the economics of integrated biorefinery operation into doubt. This chapter examines policy options that will start to address the situation from economic, environmental and social perspectives. It aims to help governments implement policy support for bio-based materials that can be consistent with that for national biofuels. This would be a cost-efficient mechanism that uses existing support policies and conditions rather than creating a separate support scheme with its own infrastructure and bureaucracy.

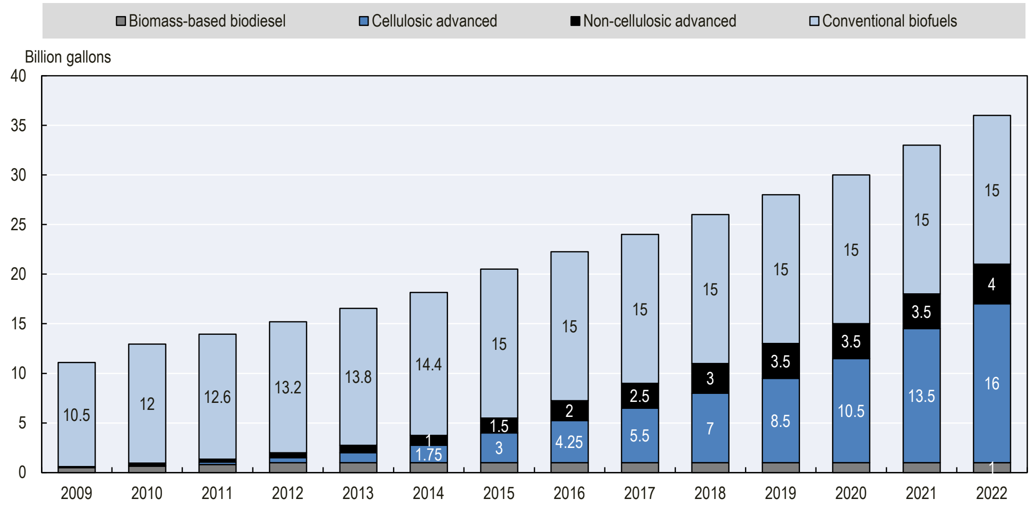
Introduction: Improving bio-based materials policy

For several years, many publications (e.g. Snyder, 2015) and events (e.g. Friends of Europe, 2012) have argued for a "level playing field" for bio-based materials (mainly bio-based plastics and chemicals). This argument refers to the large and widespread support given to biofuels and bioenergy in many countries as part of their obligations to reduce emissions of greenhouse gases (GHGs). In most countries with biofuels and bioenergy policies, public policy support for bio-based materials has been all but absent. Support that has been given has often been limited to research and development (R&D) subsidy.

Greater attention for bio-based materials is important, in large part, to make the integrated biorefineries of the future economically viable. Much of the profit would come from the lower production volumes of chemicals because their margins are generally superior to those of fuels. Not supporting bio-based materials in policy runs the risk that integrated biorefineries will not be able to function profitably.

The starting point is the US Renewable Fuel Standard (RFS). This mandates biofuels production targets through to 2022, but also sets GHG emissions targets for each category of biofuel included in the mandate (see Box 9.1). To guarantee improved environmental performance, the RFS mandates steadily increasing production of biofuels with superior GHG emissions reductions, especially cellulosic ethanol. At the same time, it allows corn-based bioethanol (first-generation bioethanol) to reach a plateau (Figure 9.1).

Figure 9.1. **Renewable Fuel Standard mandated production through to 2022**



Note: There have been notable setbacks in US biofuels production among some of the ethanol categories that have delayed policy decisions. This is particularly true of cellulosic advanced ethanol.

Source: Redrawn from US EPA (2010), "Renewable Fuel Standard Program", https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard.

Bio-based materials have a similar policy goal – to support the development of materials with better environmental performance. The greatest reductions in emissions would be gained from the bio-based equivalents of large production volume commodity chemicals. Therefore, a policy similar to RFS for materials would provide similar benefits, albeit that the scales of production are far lower than for fuels.

Box 9.1. **The Renewable Fuel Standard and mandated targets for biofuels production**

The Energy Independence and Security Act (EISA) set minimum volumes of renewable fuels that suppliers must blend into the US supply of transportation fuel each year, irrespective of market prices. This effectively guarantees a market for biofuels. The Renewable Fuel Standard 2 (RFS2) substantially reduces the risk associated with biofuels production. In so doing, it provides an indirect subsidy for capital investment in the construction of biofuels plants. As such, the expanding RFS is expected to continue to stimulate growth of the biofuels industry.

EISA requires that emissions associated with a renewable fuel are at least a certain percentage lower than those associated with the gasoline or diesel that it replaces (US EPA, 2009). EISA therefore attempts to address energy security, rural regeneration and climate change mitigation, while growing a large number of jobs in the ethanol industry.

The Environmental Protection Agency (EPA) establishes and implements regulations to ensure that the nation's transportation fuel supply contains the mandated biofuels volumes (CRS, 2013). The EPA translates the yearly volume requirements in EISA into percentage standards (sometimes called blend requirements). These are based on projections of the total amount of gasoline and diesel that will be used in that year. For example, if the projected amount was 100 billion gallons and the total renewable fuel requirement was 14 billion gallons, the EPA would set a 14% blend requirement (CBO, 2014).

To monitor suppliers' compliance with the requirements, the EPA assigns a unique "renewable identification number" (RIN) to each qualifying gallon of renewable fuel. Every RIN includes a code that identifies which of the four RFS categories – total renewable fuels, advanced biofuels, cellulosic biofuels or biomass-based diesel – the gallon satisfies. Each fuel supplier, regardless of what kind of fuel it produces or imports, must meet all of the blend requirements for a given compliance year.

The supplier achieves compliance by using the required amounts of renewable fuels itself and submitting the corresponding RINs to EPA, by purchasing RINs from other suppliers that have excess RINs to sell or by submitting RINs that it acquired in the previous year and saved for future use. For the example above, each fuel supplier would have to submit 14 RINs (including 4 for advanced biofuels and 2 for biomass-based diesel) for each 100 gallons of gasoline or diesel that it sold. Suppliers with excess biomass-based diesel RINs could either sell them or apply them towards their advanced biofuel requirement.

The huge variety of chemicals that exists compared to fuels – some 70 000 products – makes it difficult to establish a single policy for bio-based chemicals. On the one hand, making ethanol from yeast is a relatively efficient bioprocess; yeasts can achieve high concentrations of ethanol in solution, and ethanol downstream purification is tried and tested. For many other bio-based chemicals, however, this is certainly not the case. The cascading policy options outlined here attempt to address both these issues and GHG emissions.

Policy design

The policy suggestions here essentially combine elements of industrial and green growth policy. The issue is about creating new manufacturing opportunities that allow economic growth, while avoiding the trap of increased emissions (UNEP, 2010). This was at the heart of the 2009 OECD publication *The Bioeconomy to 2030: Designing a Policy Agenda*.

General points

Good policy design should ensure competitive selection processes; contain costs; and select projects that best serve public policy objectives, without favouring incumbents or providing opportunities for lobbying (OECD, 2013). This suggests the need for a portfolio of public investment where funding approaches are tailored to the different stages of technology development. The technology development spans virtually the whole range of 1-9 of Technology Readiness Levels (TRLs) as each is designed on a one-off basis. Therefore, this point for policy makers is especially pertinent – policy for bio-based materials must be flexible enough to cover a wide range of technology readiness.

In general, policies for innovation and deployment need to encourage experimentation. These experiments should develop new options that can help strengthen environmental performance at the lowest cost (OECD, 2013). Given the early stage development of bio-based materials, policies need to trigger the industry to innovate continuously. Ultimately, it needs to develop improved bio-based alternatives to achieve ambitious CO_2 emissions reductions (Saygin et al., 2014).

Governments should level the playing field between alternative options. In general, however, it should avoid championing specific technologies and solutions, emphasising competition and technology neutrality. Other sources of organic chemicals in future manufacturing should not be excluded in favour of bio-based. Nevertheless, the sources of carbon for sustainably produced organic chemicals seem limited. Petrochemical manufacturing will continue to be important, but it is ultimately unsustainable. The only foreseeable alternative sustainable source to bio-based is waste CO_2 itself, as part of the CO_2 economy (GreenFire Energy, n.d.).

Against a background that no single technology or policy will drive green innovation, Dutz and Pilat (2014) recommended that countries combine supply- and demand-side policy instruments to achieve policy goals, which may differ from country to country. This is consistent with the conclusion by Mowery and Rosenberg (1979) that instruments related to both supply and demand are necessary for innovation. The OECD publication *Demand-side Innovation Policies* (OECD, 2011) details the relationship between supply- and demand-side policy to stimulate innovation.

How to tackle thousands of different chemicals

Thousands of different chemicals are manufactured from oil. Even the list of "significant" chemicals (in terms of production volume) runs to dozens (Wikipedia, n.d.). Creating a policy support mechanism akin to the feed-in tariff used successfully for renewable electricity is nigh on impossible for chemicals. Also, there is a mere handful of large-volume liquid fuel types, which greatly simplifies creating production mandates for biofuels. Attempting production mandates for individual chemicals would most likely meet with industry resistance due to the bureaucratic burden and cost.

Carus et al. (2014) suggest an innovative mechanism that would avoid creating and administering individual mandates or quotas for large numbers of different chemicals: using bioethanol as a reference chemical. Ethanol made using certified sustainable biomass, then used to manufacture chemicals and plastics, could be counted in the same way that ethanol is counted for a biofuel. All other bio-based chemicals not derived from ethanol, such as lactic acid, could be converted to ethanol "equivalents" (e.g. calorie value or molecular weight or number of carbon atoms compared to ethanol). This simple algorithm avoids dealing with many chemicals individually.

Such an approach would imply that chemicals “larger” than ethanol (i.e. a higher calorie value; larger number of carbon atoms amount to the same thing) would have a greater subsidy. While larger number of carbon atoms may mean greater sequestration of carbon in a chemical, this is not necessarily so: not all bio-based materials are synthesised entirely of bio-based carbon. Therefore, more detailed environmental performance data for the chemical are needed for policy making. Harmonised life cycle analysis (LCA) procedures are needed to calculate the emissions savings, which would become the basis for policy support. If the molecule in question is only partly bio-based, the percentage should be made clear – this could provide the stimulus for improved bio-based content.

Setting target environmental performance threshold levels

The Renewable Fuel Standard set GHG emissions reduction thresholds for different categories of biofuels (Table 9.1). This provides the stimulus for improvements in environmental performance. Thresholds could be set for bio-based materials in a similar manner so that:

- Public R&D funds, and potentially public contributions to scale-up (through, for example, loan guarantees and other PPP mechanisms), are directed to improving environmental performance.
- Projects are selected based on combined merits of environmental and economic attributes.
- Producers are encouraged to continuously strive for improvements through funding R&D.

Table 9.1. **GHG emissions reduction values specified for the Renewable Fuel Standard**

Fuel	GHG threshold (EISA)[1]
Renewable fuel	20%
Advanced biofuel	50%
Biomass-based diesel	50%
Cellulosic biofuel	60%

1. Percentage reduction from 2005 baseline.

Note: GHG = greenhouse gas; EISA = Energy Independence and Security Act.

Source: US EPA (2009), “EPA proposes new regulations for the national Renewable Fuel Standard program for 2010 and beyond”.

However, Weiss et al. (2012) point out that large degrees of error in assessment of the GHG savings for bio-based materials is a major barrier to setting thresholds. LCA has created inconsistencies in approach, and its shortcomings have been summarised recently (OECD, 2014).

Saygin et al. (2014) selected the seven most important bio-based materials that could technically replace half of petrochemical polymers and fibre consumption worldwide. With these materials, they estimated a technical CO_2 emissions reduction potential of 0.3-0.7 Gigatonnes (Gt) CO_2 in 2030. Assuming the same potential for the remainder of organic materials production, they estimated a total technical reduction potential of up to 1.3-1.4 Gt CO_2 per year by 2030. With process improvements, they estimate 1.7-1.9 Gt CO_2 per year. These figures are compared to the emissions savings from fuel in Table 9.2.

Table 9.2. **Technical and economic potentials for CO_2 emissions reductions in 2030 and 2050**

Gt CO_2 per year

Biomass use	Technical potential (with autonomous improvements)		Economic potential (with energy efficiency)	
	2030	2050	2030	2050
Feedstock	1.3-1.4	1.7-1.9	0.3-0.4	0.6-0.7
Fuel	3.2-3.7	3.4-4.1	0.8-1.0	1.3-1.6
Total	4.5-5.1	5.1-6.0	1.2-1.3	1.9-2.2

Note: These potentials exclude biomass use in the pulp and paper sector.

Source: Extracted from Saygin et al. (2014), “Assessment of the technical and economic potentials of biomass use for the production of steam, chemicals and polymers”.

Overall, in terms of generating steam, they conclude that some bio-based materials score better than biomass, while others score worse. Therefore, in the near future, policies have to reflect this variability, recognising that biomass supply will be limited. Decisions can be made based on efficiency of use and best use of public money, and provide guidance to business and consumers.

Table 9.1 suggests threshold levels of RFS for a first draft of a tool that could help governments make specific decisions. Further research would elucidate if these are appropriate levels. In the immediate term, these levels would allow seamless entry of bio-based materials into biofuels policy. Such a policy should be kept flexible to take account of future innovations to prevent inappropriate lock-in. In other words, future developments are likely to drive improved GHG emissions reductions. Policy should allow for change in threshold values to drive these improvements.

Taking account of production volume

The production volume of a chemical becomes relevant when considering its environmental impact through total emissions savings: as production volume increases so do potential savings. LCA may determine that a chemical has great potential for GHG savings. However, if it is a high-value chemical of low production volume, it has a limited overall contribution in terms of tonnes of CO_2 saved per year.

The nascent bio-based industry has come up against a serious barrier that creates a conundrum for policy making. Trying to make a high-volume, bio-based equivalent of a petrochemical suffers two large impediments.

First, over decades, the petrochemical equivalent has had its production process and supply chains perfected and the production plants have been amortised; as a result, it benefits enormously from economies of scale. A bio-based equivalent would find it difficult indeed to compete on price. It would be easier to compete on price with a low-volume, high-value chemical.

Second, bioprocesses are notoriously inefficient when it comes to scaling up to a level that can influence a market. Microorganisms have not evolved to work in the severe environment of a bioreactor. Hence, serious modification is virtually always required to achieve the titre and yield necessary to make it economical. This modification is an iterative process that can have long innovation cycles to achieve high efficiency: it took the industry giants DuPont and Genencor approximately 15 years and 575 person years to develop and produce 1,3-PDO (Hodgman and Jewett, 2012). It takes on average 7.4 years to launch a bio-based product (Il Bioeconomista, 2015).

Naturally, small companies trying to make a bio-based chemical commercially opt for high-value chemicals that have low enough production volume to influence the market. But there is a conundrum. For policy makers, replacing the oil barrel requires bio-based alternatives to the major petrochemicals such as ethylene and other short-chain olefins.

As a policy option, one stage in decision making could allow for total global production volume that triggers a threshold for policy support: lower support for lower production volume, greater support for higher volume. This makes sense in the policy setting as greater production volume means greater potential GHG emissions saving, therefore higher value in climate change mitigation. This option is particularly attractive for nations using the mechanism to help meet emissions targets; it should act as the sought-after R&D stimulus for companies to make process improvements. This, in turn, will lead eventually to large-volume bio-based equivalents becoming competitive at scale.

Such a strategy would, of course, differ in different countries. For some countries, a balanced portfolio of investments in high and low production volume products is already a high priority.

Production efficiency factors

By specifically increasing the titre (g per litre of product), yield (g product per g substrate, normally glucose) and productivity (g per litre per hour), manufacturers and policy makers obviously benefit. This is preferred to industry and policy being at loggerheads. Lower water and energy requirements are the major outcomes, which mean improved sustainability, with two-way benefits. Here are some examples why:

- Lower volumes of water to recycle and treat can mean lower CO_2 emissions, especially if biological wastewater treatment is involved.
- Lower energy requirements are needed for smaller bioreactors with less water as the final product is more concentrated at the end of fermentation.
- Less water must be pumped around, less energy is required for reactor heating and/or cooling.
- Less energy is required for cleaning in place and sterilisation in place.
- Down-time between batches would be lower, and maintenance turnaround quicker.
- Higher titre means the product is more concentrated, so the process requires less energy input for downstream processing (purification from a very dilute solution can be enormously expensive).

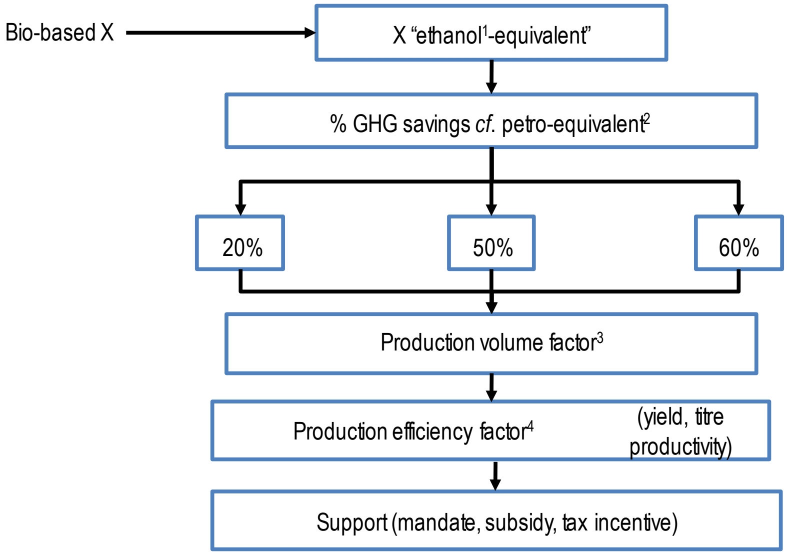
What is more, creating a factor that improves production efficiency in this manner stimulates the research that policy makers want – research leading to lower marginal production cost. And, rather than paying through a subsidy, R&D tax credits or production tax credits may be able to cover public cost, depending on eligibility. This, in the longer term, would be a more palatable mechanism than mandated production.

It is not enough to modify the hardware of the bioprocess to bring about improvement. Biocatalyst genetic engineering and synthetic biology are likely to take improvements much further than can be achieved with reactor design. For example, consolidated bioprocessing (CBP) refers to combining lignocellulosic conversion to fermentable sugars[1] within the same microorganism that converts the sugars to bio-based products. CBP technology is widely considered the ultimate low-cost configuration for cellulose hydrolysis and fermentation (US DOE, 2006).

Summary

A cascading policy support mechanism (Figure 9.2) would bring bio-based materials under the umbrella of biofuels support. Its construction addresses both environmental performance and cost-efficiency for the taxpayer. It could also stimulate R&D towards making the most efficient bio-based chemicals (in terms of GHG emissions reductions) in the most efficient bioprocess (in terms of cost for the manufacturer). It specifically addresses high-volume, low-value chemicals because these have the greatest impact in replacing the oil barrel and in emissions reduction. These are precisely the chemicals that do not attract the young bio-based industry due to the difficulty to synthesise them efficiently at scale in competition with the petrochemicals industry.

Figure 9.2. **A generic decision support cascade for embedding bio-based materials policy support within biofuels support**



1. Consider also "lactic acid-equivalent".

2. EISA biofuels reference: renewable fuel = 20%, advanced biofuel = 50%, biomass-based diesel = 50%, cellulosic biofuel = 60%.

3. Small volumes will not have significant total GHG emissions savings, i.e. they are inefficient.

4. Encourages innovation to improve efficiency.

Note: GHG = greenhouse gas.

Strengths

- This rationalises the potentially many chemicals into a single equivalent that is the industry standard (bioethanol) and that already exhibits high bioprocess production efficiency.
- It includes two measures designed to improve environmental performance. The first, in this generic scheme, uses the same GHG emissions standards as in the model biofuel policy (RFS), but is adaptable to any national/regional standards. The second takes account of the potential global GHG savings for any particular chemical that can be easily derived using the global production capacity. Both measures allow flexibility in the event of changes to GHG emissions standards and/or global production tonnages.

- It should drive innovation to improve the efficiency of bioprocesses for large-volume, low-value chemicals, precisely the ones that are most difficult without policy.
- It should make best use of public money by removing replication of bureaucracy.
- It would avoid or minimise some significant issues around ethanol as a biofuel due to, among other things, the much smaller production volumes of chemicals compared to fuels. Examples are imagined or real food prices impacts;[2] blend wall is not an issue; limited impacts on transportation infrastructure (e.g. no need for new pipelines) and no fuel stations infrastructure issues; less complex demand-side issues (e.g. no flex-fuel vehicles).

Mitigating the weaknesses

- As it stands, the cascade does not include two important technology categories for renewable chemicals: those produced through waste CO_2, and those that can be produced either entirely by "green chemistry" or by a combination of bio-based and green chemical technologies. However, if the GHG emissions reductions for chemicals produced by these technologies are known, they should be rather easily incorporated into the scheme. The best example is bio-based ethylene, the synthesis of which involves fermentation to ethanol followed by chemical conversion to ethylene.
- It does not specify eligibility for entry to the scheme. However, it is intended for production rather than R&D, although eligibility for chemicals that need some near-market R&D is suggested, depending on state-aid rules. Therefore, it would seem sensible to make the scheme eligible to chemicals at a TRL of 7 and above in the US Department of Defense classification (US DOD, 2011). Or simply, the policy could specify technologies that are "beyond demonstration".
- The chemicals described are identical, drop-in replacements for petrochemicals, and therefore are not "needed" as such. In RFS, ethanol is desirable in petrol (gasoline) as a fuel oxygenate. Therefore, this would justify the petrochemicals industry accepting such a policy.
- Such a policy cannot be brought in for many bio-based chemicals as few are produced at volume. This is part of the reason for the policy – to stimulate greater production of a greater number of bio-based chemicals. Therefore, a phased approach would be needed. Each country would need to decide which chemicals to concentrate on, and slowly add to its inventory by keeping the policy flexible. This could be co-ordinated with a national bioeconomy strategy and/or a national biorefinery roadmap. However, it would be difficult to specify a date when the mandate ends or how the mandate may be phased out; it must do this to remove longer-term market distortion.
- The position of large polymers is not clear. Large bio-based equivalents of thermoplastics would sequester a lot of carbon, and policy may not reflect this. However, it would be reflected in the global production volume of the monomer. For example, ethylene is the largest production volume organic chemical. It is subsequently polymerised to polyethylene. If the manufacturers of ethylene and polyethylene are different, then one or the other may not qualify in this scheme. Both cannot qualify, as this would amount to double counting. This is because the polymerisation stage does not use any new bio-based carbon; it uses the bio-based carbon in the bio-ethylene.

Conclusions

Creating a level playing field between bio-based materials, biofuels and bioenergy has stayed as a defining topic in bioeconomy arguments. The potential solution laid out here in basic terms could address the need. Each country would need to develop the idea to suit its own conditions – after all, different countries have their own strengths and weaknesses. Making integrated biorefineries viable depends on balancing materials, fuels and energy production. Work by individual countries could mitigate any weaknesses. The scheme could be a cost-effective way forward as it simplifies bureaucracy and infrastructure for policy implementation.

Notes

1. One of the most significant challenges in using the vast global lignocellulose resource is the need for large quantities of enzymes to efficiently convert lignocellulose, hemicellulose and cellulose into fermentable sugars. These enzymes represent the second highest contribution to raw material cost after the feedstock itself.
2. There is a link between "imagined or real food price impacts" and food production. Specifically, one aspect surrounding corn-based ethanol is the diversion of grain for feed (primarily for cattle) to fuel. This avenue, and there could be others, can lead to price impacts.

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Meeting Policy Challenges for a Sustainable Bioeconomy

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