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Balancing the bioeconomy: supporting biofuels and bio-based materials in public policy

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Abstract

Key objectives for a bioeconomy are now embedded in the strategic activities of more than 30 countries, with an increasing number developing a national bioeconomy strategy. In a bioeconomy, fossil-based commodities and electricity start to be replaced by bio-based. This is meant to address some of the so-called 'grand challenges' being faced by society, but especially energy security (by reducing dependence on imported fossil fuels) and climate change (by reducing greenhouse gas emissions). However, in the vast majority of countries that have bioenergy and biofuels policies, there is either no policy support for bio-based materials (especially chemicals and plastics) or it is limited to R&D subsidy. And yet, studies repeatedly show that higher added value and job creation are to be found in materials production. This paper suggests a cost-effective public policy strategy to redress this balance. The strategy also addresses a weakness of bio-based production – low efficiency – by creating stimulus for companies to innovate their biocatalysts and bioprocesses.

Broader context

The 'grand challenges' of society have at their heart population growth. There are expected to be over nine billion people alive by 2050. What is more, the global middle class is due to explode in size. This brings with it increased demand for commodities, which also brings emissions: it has been estimated that a doubling of an economy results in an 80% increase in emissions. It is an attempt to break this link between economic growth and increased emissions that is an over-arching objective of a bioeconomy. These grand challenges assume the characteristics of an ecosystem – making a change in one place can have unintended consequences elsewhere. Put together, some of these interacting challenges include: climate change, energy security, soil destruction, water security, food security, ageing and increasing population. Growing energy crops to make biofuels may affect food security. Growing more crops on the same amount of arable land (intensification) can increase soil destruction and lead to more stress on freshwater supplies. There are many such interactions foreseeable. There are no easy policy answers, and this is the reality into which the bioeconomy concept was born. It is part of a much larger policy need that includes green growth and new industrial and agricultural policy in a world that promises to be very different post-fossil fuels.

Introduction

Thomas[1] highlighted just how dependent society is on fossil-based (non-renewable) resources independent of fuels and electricity. Without petroleum the modern lifestyle would be much less rich indeed. But change is coming. There is no shortage of crude oil envisaged in the near-to-medium term, but is seems highly likely now that climate change legislation will limit how much of proven reserves of oil, gas and coal can be used in the future to try to meet the 2°C global warming obligation set out in the Copenhagen Accord. McGlade and Ekins[2] have calculated that a third of oil reserves, half of gas reserves and over 80% of current coal reserves should remain unused from 2010 to 2050 in order to meet this obligation. By century end, the Intergovernmental Panel in Climate Change (IPCC) has warned that greenhouse gas (GHG) emissions need to be close to zero to achieve the 2°C obligation.

A response in many nations has been to set emissions reductions targets. Starting around the beginning of this century, the rise in importance of bio-ethanol as both a fuel oxygenate and as a biofuel can be charted. Equally many countries are looking to bioenergy to reduce emissions by replacing burning coal with burning wood. Policy support for the latter is dominated by feed-in tariffs. For biofuels the dominant policy support has been mandated production targets. The exemplar policies are the Renewable Fuel Standard (RFS)[3] of the US, and the Renewable Energy Directive (RED) of the EU[4].

Thus the conditions were enabled for a grander vision, that of a bioeconomy, and the policy agenda for a bioeconomy was set out in a landmark OECD publication[5]. Subsequently, the two highest-profile bioeconomy strategies were published by the European Commission[6] and the US[7]. Both of these and other more recent bioeconomy strategies envisage future bio-based industries producing commodities (e.g. fuels, chemicals, plastics, textiles) using biomass as the feedstock instead of fossil resources. However, the resulting public policy has been extremely heavily biased towards bioenergy and biofuels, with virtually no support given to bio-based materials other than R&D subsidy[8].

The bioeconomy vision is spreading. Importantly, some developing nations that have relied on selling their natural resources are now looking to creating a bioeconomy based on higher value production. Giants in the biomass potential sense such as India, Russia, Brazil and China currently have a ‘partial bioeconomy strategy’ in that they have policies that suggest a developing bioeconomy without having a dedicated bioeconomy strategy. Malaysia has committed to a very ambitious bioeconomy strategy (the 2012 Biotechnology Transformation Programme, BTP) that clearly demonstrates a will to transition towards higher value-added downstream activities. As part of this, Malaysia is attracting significant inward investment in bio-based production.

As some countries are struggling to meet their emissions reduction obligations, it is puzzling that the chemical sector has been relatively ignored in this respect compared to fuels and electricity. The sector is the largest industrial energy user, accounting for about 10% of global final energy use[9], and the third largest industrial source of emissions after the iron and steel and cement sectors[10]. Energy costs on average account for 50–85% of the production costs of bulk chemicals[11]. This is particularly pertinent to OECD countries as energy costs can be up to seven times higher in fuel importing nations compared to fuel producing nations. Moreover, studies repeatedly state that job creation and value-added are much greater for bio-based materials than either biofuels or bioenergy. Significant opportunities for GHG emissions savings have also been demonstrated[12] [13] [14].

This paper sets out a policy mechanism that would allow bio-based materials to take advantage of the same policies that support biofuels. This would avoid replication of a regulating bureaucracy, and would therefore be cost-effective for the public purse. The mechanism would also encourage bio-based production companies to invest in innovation to improve their biocatalysts and production processes. The suggested policy mechanism is only one part of a future bioeconomy policy mix of technology push and market pull instruments. How this wider policy mix will look is summarised by Carus et al.[15]

Policy design

Essentially the policy suggestions made here combine elements of industrial and green growth policy as it is about the creation of new manufacturing opportunities that allow economic growth and at the same time avoid the trap of increased emissions[16].

General points

Good policy design should ensure competitive selection processes, contain costs and select projects that best serve public policy objectives. In general, policies for innovation and deployment need to encourage experimentation to develop new options that can help strengthen environmental performance at the lowest cost[17]. Given the early stage development of bio-based materials, policies need to trigger continuous innovation by the industry sector to develop improved bio-based alternatives in order to achieve ambitious CO_2 emissions reductions[18]. However, with time, process improvements should result from these policies, and it would be prudent then to phase them out to prevent market distortion.

How to tackle large numbers of different chemicals

The list of chemicals manufactured from oil is enormous. Even the list of 'significant' chemicals (in terms of production volume) runs to dozens[1]. Meanwhile, the number of types of large volume liquid fuels is a mere handful. This simplifies creating production mandates for biofuels greatly. To try this with individual chemicals would most likely meet with resistance from the industry due to the bureaucratic burden and cost it would create.

Carus et al.[19] described an innovative solution. Their suggested mechanism that would avoid creating and administering individual quotas for large numbers 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. All other bio-based chemicals that are not derived from ethanol, such as lactic acid, could be converted to ethanol "equivalents", on the basis of a metric such as calorie value or molecular weight, in comparison to ethanol.

Setting target environmental performance threshold levels

The Renewable Fuel Standard set GHG emissions reduction thresholds for different categories of biofuels (Table 1). 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 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 1. GHG emissions reduction values specified for the Renewable Fuel Standard.

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[1] A glance at the 'Petrochemical' entry in Wikipedia gives an indication of this diversity (http://en.wikipedia.org/wiki/Petrochemical)

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

Source: US EPA[20]. * Percentage of reduction from 2005 baseline. 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. The EISA also requires that the emissions associated with a renewable fuel be at least a certain percentage lower than the emissions associated with the gasoline or diesel that the renewable fuel replaces.

However, a major barrier to setting thresholds for bio-based chemicals exists due to large degrees of error in assessment of the GHG savings for bio-based materials, as highlighted by Weiss et al.[14]. Life cycle analysis (LCA) has created inconsistencies in approach, and thus a lack of confidence in the outcomes.

Saygin et al.[17] selected the seven most important bio-based materials that could technically replace half of petrochemical polymers and fibre consumption worldwide, and estimated a *technical* CO_2 emissions reduction potential of 0.3 – 0.7 Giga tonnes (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, compared to 3.2-3.7 Gt for fuels.

Not supporting bio-based materials in public policy, then, is to miss significant opportunities for GHG savings. It would also make the economics of integrated biorefineries questionable as the margins for many chemicals are usually better than for high-volume fuels[21]. At times of high oil prices the margins on fuel production are notoriously thin.

As a first attempt, the threshold levels of RFS given in Table 1 are suggested. Publications suggest these emissions savings from bio-based chemicals are entirely feasible. Further research is required to decide if these are the most appropriate levels. However, in the immediate term, this would allow seamless entry of bio-based materials into biofuels policy. Moreover, the added costs to existing biofuels programmes would be low or negligible due to the low production volumes of chemicals compared to fuels. Such a policy should be kept flexible as future developments are likely to drive improved GHG emissions reductions. Policy should allow for change in threshold values in future to act as a driver for these improvements.

Taking account of production volume

The production volume of a chemical becomes relevant when considering its overall environmental impact. LCA may determine that a chemical has great potential for GHG savings, but if it is a high-value chemical of very low production volume, its overall contribution in terms of tonnes of CO_2 saved is limited. For example, *cis*-3-hexen-1-ol, a high-value chemical with the smell of ‘cut grass’, has a total annual production volume of around 30 tonnes. A bioprocess leading to a reduction in its CO_2 emissions would not qualify in the proposed mechanism as the contribution to global GHG emissions reductions would be negligible. In such cases setting a production volume target is not efficient. However, the small companies trying to make a bio-based chemical commercially often opt for high-value chemicals with low production volume. In such cases, market entry would be without subsidy and would be entirely dependent on a competitive price.

For the policy maker, replacing the oil barrel requires bio-based alternatives to the major petrochemicals such as ethylene and other short-chain olefins. However, trying to make a high-volume bio-based equivalent of a petrochemical suffers two large impediments:

1. Over decades the petrochemical equivalent has had its production process and supply chains perfected and the production plants have been amortised, so that it benefits enormously from economies of scale;

2. Bioprocesses are notoriously inefficient when it comes to scaling up to a level that can influence a market. Process and biocatalyst modification is virtually always required. This modification is an iterative and expensive process: it took industry giants DuPont and Genencor approximately 15 years and 575 person years to develop and produce bio-based 1,3- propanediol (PDO)[22].

As a policy option, it is suggested that a stage in the decision making should be based upon making an allowance for total global production volume which triggers a threshold for policy support: lower support for lower production volume, greater support for higher volume. This makes sense in the current policy setting as:

- Greater production volume means a greater contribution to national GHG emissions reduction targets;

- It should act as the sought-after R&D stimulus for companies to make process improvements that make further GHG savings.

Production efficiency factor

By specifically increasing the titre (g per litre of product), yield (g product per g substrate, often glucose) and productivity (g per litre per hour), the manufacturers and the policy makers benefit. Smaller reactors and lower water and energy requirements are the major outcomes, which mean improved sustainability. Here are some reasons why.

- Lower volumes of process and cooling water to recycle and treat can mean lower CO_2 emissions, especially if biological wastewater treatment is involved.

- Less energy is required for cleaning in place (CIP) and sterilisation in place (SIP) in smaller bioreactors.

- 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 and manufacturers want – research leading to lower marginal production cost. As an alternative policy instrument for the longer term, it may be possible for the public cost to be met indirectly through R&D tax credits or production tax credits, or equivalent indirect instruments as appropriate to a particular country. This would be a more palatable mechanism than indefinite mandated production targets: these would be better to be phased out according to a timetable as in the Renewable Fuel Standard. Mandated production targets are often criticised for distorting markets, and are therefore better to be restricted to the earliest phases to establish market presence. Subsequent indirect mechanisms could bridge the gap till the point is reached when market forces alone should determine market share for a bioprocess. The failure to phase out subsidies creates true long-term market distortion, such as caused by fossil fuel consumption subsidies.

For example, there is much process improvement to be had through synthetic biology efforts in consolidated bioprocessing (CBP), which refers to combining lignocellulosic conversion to fermentable sugars within the same microorganism that converts the sugars to bio-based products. The US Department of Energy (USDOE) endorsed the view that CBP technology is widely considered the ultimate low-cost configuration for cellulose hydrolysis and fermentation[23].

Glucaric acid: identified as a top value-added chemical from biomass more than a decade ago, but yet to reach the market

Glucaric acid is a good example that highlights central issues. It has applications as a specialty chemical, but its biggest bulk applications are its potential use as a building block for a number of polymers, including new nylons[24]. Therefore it catches the attention of policy makers for both its economic potential and its ability to contribute to GHG emissions reductions. For these and other reasons, D-glucaric acid has been identified as a "*top value-added chemical from biomass*"[25].

Its large scale production through synthetic chemistry has been hindered, primarily due to competing side reactions which result in a relatively low conversion of the feedstock, glucose, to D-glucaric acid (<50% yield)[26]. There is a natural biochemical route in mammals but it has too many steps for an industrial production, and therefore most effort has been focused on designing a microbial pathway.

Metabolic engineering publications often demonstrate huge potential for improvement in titres and yields. In 2009 Dueber et al.[27] reported a 200-fold increase in glucaric acid titre, but still to only 1.7 g per litre. Raman et al.[28] achieved a 22-fold over their *E. coli* parent strain; however, absolute production of glucaric acid remained substantially lower (1.2 mg per litre) than previously reported titres. Despite much elegant metabolic engineering in *E. coli*, available yields through microbial processes are still way too low: Schiue[29] further improved titres, but a variety of strategies never achieved more than 5 g per litre. For very high value, low production volume chemicals these yields may work. For high-volume commodity chemicals of low value, however, the downstream purification from such low concentrations and the subsequent wastewater treatment costs make it highly unlikely that a bioprocess can be competitive. Compare this to efforts with lactic acid: a recent review of metabolic engineering studies for its bio-based production[30] cited many studies with titres well over 100 g per litre and yields in excess of 90%.

So glucaric acid exemplifies some of the central hopes and difficulties in bio-based production: hopes for economic and environmental improvements as a commodity chemical, and difficulties due to the classic bioprocess limitations in production efficiency. The entire industry needs technical breakthroughs to reduce the innovation cycle time in order to compete with synthetic chemistry.

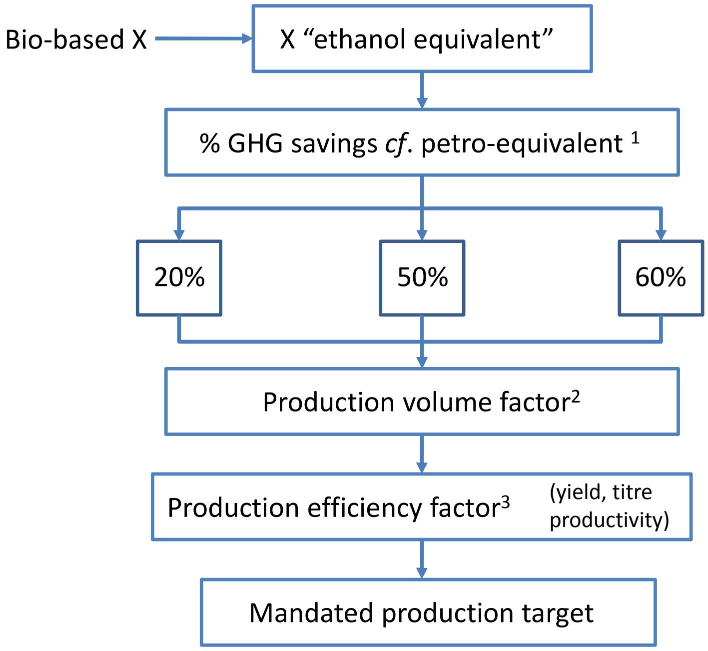
With reference to the proposed policy mechanism, glucaric acid would be eligible on the basis of the potential for significant GHG emissions savings (in high production volume commodity chemicals applications). Incentivising its production efficiency through R&D support would hasten the point where it would compete in the market place without public policy support.

Summary

A cascading policy support mechanism (Figure 1) is suggested that would align the policy goals of bio-based materials with those of biofuels. It is constructed in a way that addresses both environmental performance and cost-efficiency for the taxpayer. It is suggested that it would also stimulate R&D in the direction of 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 are unattractive to the young bio-based industry as it is extremely difficult to synthesise them efficiently at scale in competition with the petrochemicals industry.

Such a mechanism should retain ultimate flexibility to reflect changing circumstances e.g. as mandated production targets are met, it should be possible for indirect instruments such as tax credit schemes to take over as the former are phased out. Ultimately, as market competitiveness is achieved, all forms of public support would be removed.

Figure 1. A generic decision support machanism to align policy goals for bio-based materials with those for biofuels.



[1] **EISA biofuels reference**

Renewable fuel	20%
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[2] Small volumes will not have significant total GHG emissions savings ⇒ inefficient

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Disclaimer statement

The opinions expressed and arguments employed herein are those of the author and do not necessarily reflect the official views of the Organisation for Economic Cooperation and Development (OECD), or of the governments of its member countries.

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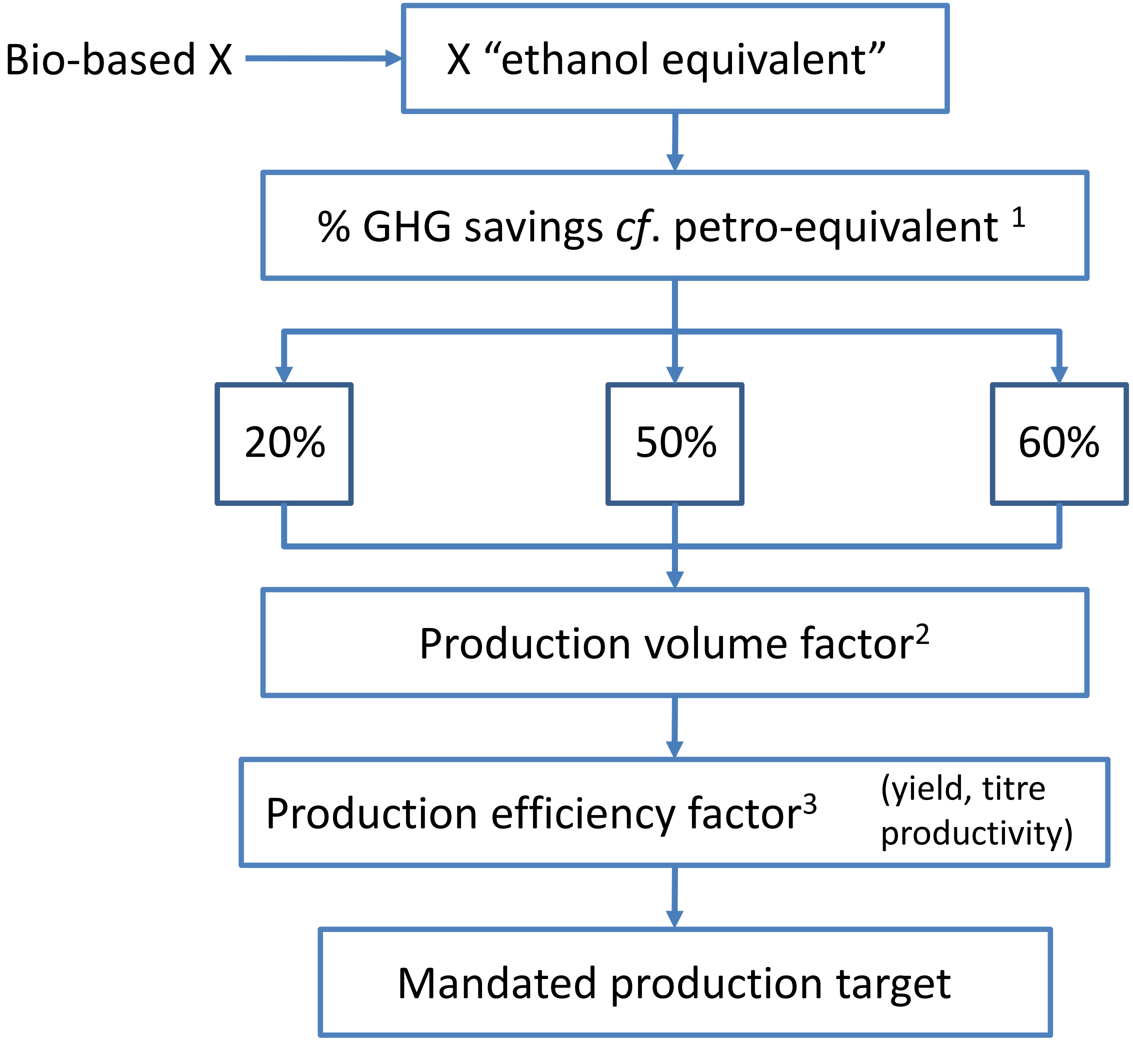

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