Innovation in the bioeconomy

Rationale and objectives

The bioeconomy encompasses industrial biotechnology, other modern biotechnologies, green chemistry, bio-based production and biomass production, and recent policy is aiming to develop the bioeconomy as part of the broader effort to achieve sustainability. However, the bioeconomy can mean more, e.g. pulp and paper production, even farming. How it is defined does make a difference.

The recognised products of industrial biotechnology are biofuels, bioenergy and bio-based materials such as chemicals, plastics and textiles. This represents a major transformation in production, from a fossil base (oil, gas and coal) towards production based on renewable resources, principally renewable carbon. The rationale for this shift in production is enshrined in several of the so-called "Grand Challenges" facing society: food security, energy security, climate change and resource depletion. As it has become clear that fossil fuel utilisation, the underpinning basis of modern society, is inextricably linked to climate change and global warming, the search has been on for new forms of energy and materials.

Biofuels and bioenergy (electricity) policies are part of many nations' policies on energy security and climate change mitigation (OECD, 2014a). In Europe, the Renewable Energy Directive (EU, 2009) has been a major policy driver. In the United States, the Renewable Fuels Standard (RFS) set off the new race to first-generation ethanol, and it is now setting the goals for second-generation (cellulosic) ethanol (Federal Register, 2010).

As some countries are struggling to meet their emissions reduction obligations, the chemical sector has been less subject to bio-based policy compared to fuels and electricity. The sector is the largest user of industrial energy, accounting for about 10% of global final energy use (Broeren et al., 2014), and it is the third-largest industrial source of emissions after the iron and steel and cement sectors (IEA, 2012). Energy costs on average account for 50-85% of the production costs of bulk chemicals (UNIDO, 2011). This is particularly pertinent to OECD countries, as energy costs can be up to seven times higher in fuel-importing nations than in fuel-producing nations. Moreover, studies repeatedly state that job creation and value added are much greater for bio-based materials than for either biofuels or bioenergy. Significant opportunities for savings in GHG emissions have also been demonstrated (Hermann et al., 2007 and 2011; Weiss et al., 2012).

Nevertheless, there have been a few policy success stories for bio-based chemicals already, for instance in Japan. Following the ratification by the Japanese Government of the Kyoto Protocol in June 2002, the government announced (December 2002) two measures: the Biotechnology Strategic Scheme and the Biomass Nippon Strategy. The main objective of the two measures was to promote the utilisation of biomass and to reduce the consumption of fossil resources and mitigate global warming through the use of biotechnology. The Biomass Nippon Strategy requires that 20% of all plastics consumed in the country be sourced renewably by 2020. This prompted companies such as Toyota and NEC to accelerate their levels of research and development into bio-based plastics and to raise the bio-based content of their products (OECD, 2013).

Major aspects and instruments

Given the large scale of national and international policies on bioenergy and biofuels, there has been very little public policy targeting bio-based chemicals and plastics beyond R&D subsidy. The model envisaged for the future is the integrated biorefinery, where chemicals, fuels and electricity are made at a single facility. Excluding bio-based chemicals from public policy creates problems for the economics of running integrated biorefineries. The issues were reviewed recently (OECD, 2014a).

Synthetic biology in a bioeconomy

Many definitions of what synthetic biology actually is have been proposed. The following is an operational definition for Europe created through the work of SCENIHR (2014).

"SynBio is the application of science, technology and engineering to facilitate and accelerate the design, manufacture and/or modification of genetic materials in living organisms."

One of the first areas of application of synthetic biology was bio-production. The production of semi-synthetic artemisinin, a potent anti-malarial, from microbially sourced artemisinic acid is one of the first success stories for the combined use of metabolic engineering and synthetic biology in the production of a pharmaceutical on an industrial scale. A bio-based version of propanediol reached commercialisation through synthetic biology. A new route to vanilla is through fermentation using a synthetic biology yeast strain, another synthetic biology product now on the market.

Synthetic biology remains controversial in some parts of the world, in particular with regard to biocontainment and biosecurity. Risk assessment for synthetic biology is an evolving policy field, but to date the overall governance and regulation of the application of synthetic biology to industry is still not satisfactory. There is a need to update the biotechnology regulatory regime to streamline and speed up the transfer of research into new products.

The policy issues pertaining to synthetic biology are much the same as those concerned with genetic modification, and these have been reviewed recently (OECD, 2014b).

Biomass sustainability

This may be the greatest policy challenge of all for the bioeconomy. All of the efforts in bio-based production and the bioeconomy depend on the long-term sustainability of using biomass as a feedstock for industrial production. Renewability is certain; sustainability is far from proven. The stark reality of the current situation regarding biomass sustainability can be summed up in two sentences. There is an expectation that all forms of biomass will be the "feedstocks of the future", and central to a Next Industrial Revolution. At the same time, there are currently no comprehensive or standard definitions of sustainability, no ideal tools for measuring it, and no international agreement on the set of indicators to derive the data from which to make measurements (Bosch et al., 2015). Furthermore, these matters need to be harmonised internationally to prevent trade barriers.

Another concern is the prevention of international biomass disputes. Biomass disputes can arise over relatively trivial matters, such as the situation that arose between Canada and the EU over a definition of primary forest. Such disputes are usually amenable to mediation. More serious could be disputes over critical bioeconomy crops, such as the oil palm. This was clearly highlighted by the removal of four major Asian groups from the Norwegian sovereign wealth fund in August 2015 over deforestation in Indonesia. One suggestion is to set up an international facility to settle biomass disputes.

It has also been suggested to develop a sustainable biomass platform. The idea for a biomass platform is quite simple. Biomass producer and consumer countries would be able to meet on a regular basis to discuss and iron out problems to head off potential conflicts and trade barriers. The feasibility of such a platform is currently being investigated.

Biorefinery models and policy

For public policy makers in science and technology, building biorefineries is a significant departure. Where programmes to award grants for upstream research were relatively inexpensive, these new demonstrator and commercial facilities are much more costly and also high risk. The private sector needs stable, relatively long-term policy to invest. To de-risk private investment, public-private partnerships (PPPs) have been used. The US and Europe have seen quite different approaches to PPPs. The method of financing a complex construction project like a biorefinery has a dramatic effect on how the project can be executed. Obstacles posed by debt management, for example, may be alleviated by the provision of loan guarantees, which is the PPP route of preference in the US. Loan guarantees have not been implemented in Europe, but provisions are being made for this.

Great emphasis has been placed on rural locations for rural regeneration. However, that may conflict with other policies such as brownfield utilisation. Public opinion is also a serious concern when building rural biorefineries. There may also be a shortage of the required skills in rural locations, and infrastructure and transport conditions may not be adequate. Attention has to be paid to feedstock logistics, as the supply chains are more complex than for the fossil counterparts: Europe alone has some 16 million forest owners and 14 million farm owners (Hetemäki, 2014). The process requires coordination with a large numbers of

stakeholders, and local authorities face difficult decisions. Close coordination between national and regional authorities is also needed.

Job creation is generally a policy priority. A policy goal for some OECD countries is re-industrialisation. The chemicals industry is estimated to have a large multiplier of indirect jobs, due to long complex supply chains. This is also true of biorefining. Crucially, complex bio-production supply and value chains call for local jobs, not for transporting feedstock over oceans. A large new biorefinery being constructed in Finland will have only 200 jobs actually in the facility, but it is estimated that there will be 2 500 jobs in the value chain, 1 500 of which will be new jobs. These involve creating the “industrial ecosystem” logistics for growing, harvesting and transporting biomass.

Substituting oil

One obstacle facing governments has been scepticism about the ability to make large numbers of different chemicals from biomass to ultimately replace the oil barrel. With biofuels, there is only a handful of liquid fuels to replace. But there are at least hundreds of organic chemicals in everyday use. A very significant shift in bio-based production trends has occurred recently.

Not so many years ago, the literature concentrated on chemicals such as lactic acid and propanediol. To the public, these terms and products are invisible. Now, there is a growing number of bio-based products that are everyday items familiar to the public: tyres, bottles, spectacles, smart phone touch screens, biopharmaceuticals, fragrances, flavours, cosmetics, sweeteners, glue, lubricants, bioactives in detergents, fabrics (El-Chickali et al., 2016). The difficulty is to make all such products at scale.

A recent report (EC, 2015b) lists over 90 bio-based materials with a technology readiness level (TRL) of at least 3, of which over 20 are at TRL 8.5. Moving from TRL 5 to TRL 8 still can take an inordinate amount of time, and may spell the death of projects that hold great promise. This is one area where favourable public policy support could intervene: supporting R&D in synthetic biology is one way to reduce the innovation cycle time. TRL levels are now finding their way into public policy as a reference point for discriminating levels of support.

A potent symbol of the rise of industrial biotechnology is government support for capacity building, especially in the form of competitive clusters. Although the efficiency of publicly funded clusters is contested, the model is appropriate to industrial biotechnology given the wide range of stakeholders involved, from farmers to small and big industry, and the large expense of biorefinery facilities. The policy goal of rural regeneration dictates that farmers and farmers’ cooperatives must be involved. The cluster model has been emphasised in Europe. The largest concentrations are in the triangle of Belgium, the Netherlands and northwest Germany – in the heart of the European chemicals industry. The industrial biotechnology cluster model has already evolved into international clusters.

Table 1. Innovation in the bioeconomy: typology of national and international policy initiatives and country examples

National STI policy initiatives		
Governance	Dedicated national strategy/ plan	Colombia (Colombia BIO), Finland (Bioeconomy Strategy), France (upcoming Bioeconomy Strategy), Germany (National Research Strategy Bioeconomy, National Policy Strategy), Japan, Norway (Bioeconomy Strategy), Russian Fed (BIO2020), South Africa (Bioeconomy Strategy), Spain (Spanish Strategy on Bioeconomy, forthcoming), US (US Bioeconomy Blueprint), EC (EU Bioeconomy Strategy).
	Priority in broader national STI strategy/ plan	Japan Biomass Nippon Strategy of 2002, US Farm Security and Rural Investment Act, US Agricultural Act of 2014 US Renewable Fuels Standard, EU Renewable Energy Directive.
	As part of related national strategies	Finland (National Forest Strategy 2025), Italy (Strategic Plan on Innovation and Research for the agricultural food and forestry system).
	As part of a smart specialisation strategy	Croatia (Smart Specialisation Strategy), Poland (National Smart Specialisation).
	Coordination at national level (e.g. regions, ministries)	Germany (German Bioeconomy Council), UK (Synthetic Biology Leadership Council), US (Biotechnology Industry Organization).
	Strategic public-private partnerships	US (Department of Agriculture and Department of Energy), European Commission (Bio-Based Industries).
	Regulation	United States (Toxic Substances Control Act), European Union (REACH regulation).
	Meta-instruments (e.g. risk assessment, indicators)	Korea (Korean Bioplastics Association), Japan (Bioplastics Association), European Bioplastics, US (BioPreferred Program), EC (Scientific Committee on Emerging and Newly Identified Health Risks SCENIHR).
Direct funding to bioeconomy actors	Subsidies	Brazil (Research Council funding programmes), Canada (ecoAgriculture Biofuels Capital Initiative, ecoENERGY for Biofuels Initiative); Finland (TEKES Bioeconomy programme), France (Environment Agency, ADEME, Investissements d'Avenir), Germany (National Research Strategy Bioeconomy), Norway, (RCN research programmes: BIONÆR, BIOTEK2021, HAVBRUK, ENERGIX; Innovation Norway biorefinery and bioenergy programmes), Spain (RETOS investigacion programme), US (DARPA 1,000 molecules programme).
	Loan guarantees	US (Department of Agriculture and Department of Energy).
Platforms & infrastructures	Transport	US (Ethanol pipeline, Florida).
	Infrastructures and facilities (incl. demonstrators, incubators, etc.)	Finland (VTT, Key projects bioeconomy and clean solutions programme), France (Bazancourt-Pomacle, CIMV, Toulouse White Biotechnology), Germany (Leuna), UK (Centre for Process Innovation, IBioIC - Scotland).
	Clusters	Belgium (CINBIOS), France (hub BRI, IAR, Pôle Eco-Industries de Poitou-Charentes), Germany (BIOCATALYSIS2021, Biopolymere/Biowerkstoffe, CIB Frankfurt, CLIB2021, Industrielle Biotechnologie Bayern Netzwerk, Rhein-Main Cluster Chemie und Pharma, BioEconomy Cluster Halle), Italy (Green Chemistry Cluster: SPRING), Netherlands (BE-Basic), and UK (BioVale), International (BioInnovation Growth mega-cluster of NRW, Flanders and The Netherlands).
Skills	Education	Germany (website Biooekonomie.de), Netherlands (MOOC: Industrial Biotechnology edX, TU Delft).
	Broad culture of bioeconomy	Germany (website Biooekonomie.de).
Cross-border governance arrangements		
Governance	Guiding documents and action plans	UN Sustainable Development Goals (2015), Climate Change Paris (2015), EC Circular Economy (2015).
International funding programmes		Peru (ERANet-LAC - Network), EU (BESTF 2, ERA-IB, ERA-IB-2, ERA-NET BIOENERGY, many ERA-NET Cofund topics in the Bioeconomy).

Note: This table draws upon recent analytical works on the innovation policy mix carried out for the *OECD STI Outlook* under the aegis of the OECD Committee for Scientific and Technological Policy (Kergroach et al., forthcoming). Country information is drawn from the EC/OECD International Science, Technology and Innovation Policy (STIP) Database, edition 2016, https://www.innovationpolicyplatform.org/topic-menu/sti-policy-database, and OECD (2013; 2014a and 2014b).

Recent policy trends

There are many overlapping policies that pertain to the bioeconomy, which could lead to problems with the duplication of effort, lock-ins, U-turns, inefficient trade-offs, trade barriers, etc. The most significant requirement for policy alignment and coordination in bioeconomy policy is the reconciliation of food security and the industrial use of biomass. Only a few of the most visible trends are mentioned here.

Around 50 countries have made the bioeconomy part of their economic and innovation strategy (Figure 1), including all of the G7 and the European Union (Bioökonomierat, 2015). Dedicated bioeconomy strategies are less common, but the number is growing. Germany, the US and Japan have set ambitious goals in specific national bioeconomy strategies, while France (soon to have its own bioeconomy strategy), the UK, Italy and Canada also provide significant support for the development of the bio-based economy in practice. Landmark documents include the US Bioeconomy Blueprint (The White House, 2012) and the European Union bioeconomy strategy (European Commission, 2012).

Different national bioeconomy strategies reflect specific national exigencies. South Africa's bioeconomy strategy (Government of South Africa, 2013) places great emphasis on health, while Finland's (Government of Finland, 2014) emphasises the use of wood as a feedstock for industrial production – Finland will soon have 29 biorefineries, already built or under construction.

Figure 1. Status of bioeconomy strategies globally, 2016

Source: German Bioeconomy Council.

UN Sustainable Development Goals, 2015

The bioeconomy remains a relatively unknown term outside the related policy and science communities. And yet its ambitions are a very good fit with sustainable development. El-Chichakli et al. (2016) described how the bioeconomy and bio-based technology could be aligned with, or integrated into, more than half of the UN Sustainable Development Goals (UN Sustainable Development Platform, 2016).

EC Circular economy, 2015

In 2015, the European Commission launched an action plan for a circular economy (EC, 2015a), in which the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste is minimised. This is another major policy action that is consistent with a vision of a sustainable future. A key objective of biorefining, especially for second-generation biofuels and bio-based materials, is the valorisation of waste (Fava et al., 2015).

Climate change and Paris, 2015

The climate deal achieved in Paris in 2015 has been hailed as the biggest policy breakthrough in climate politics yet. In common with bioeconomy goals, the agreement reached in Paris aims at reducing the carbon pollution that threatens the planet and creating more jobs and economic growth driven by low-carbon investments. It is hoped that the Paris Agreement (UN FCCC, 2015) is sufficiently robust that the transition to a low-carbon economy is now unstoppable.

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