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## Working Party on Biotechnology, Nanotechnology and Converging Technologies

# BUILDING A SUSTAINABLE BIOECONOMY: A FRAMEWORK FOR POLICY

*This report partially fulfils the requirements of Module 3.1 Bio-production, Theme 3.1.3 Replacing the Oil Barrel, of the Programme of Work and Budget (PWB) of the BNCT for Biennium 2015-2016, see Figure 1 of [DSTI/STP(2014)39].*
*Delegates to the BNCT are requested to:*
*·Note and comment on the paper at the meetings of the Working Party on BNCT of December 05-07, and;*
*·Submit written comments by January 16, 2017.*

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**NOTE BY THE SECRETARIAT**

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# BUILDING A SUSTAINABLE BIOECONOMY: A FRAMEWORK FOR POLICY

## Introduction

> "*The twin defining challenges of our century are overcoming poverty and managing climate change. If we can tackle these issues together, we will create a secure and prosperous world for generations to come. If we don't, the future is at grave risk*".

Stern (2016).

1. Policy momentum has been building for over a decade for the development of a bioeconomy, fuelled in part by the landmark publication in 2009 of *The bioeconomy to 2030 – designing a policy agenda* (OECD, 2009). Events of 2015 propelled the bioeconomy concept to the forefront of politics: COP21, the UN Sustainable Development Agenda and its seventeen goals, and the Global Bioeconomy Summit. These events are in response to the toughest challenges of this generation, the so-called grand challenges of climate change, energy security, food and water security and resource depletion. However, the bioeconomy is aligned naturally with more mainstream policy, such as knowledge-driven growth, circular economy, smart specialisation, green growth and rural regeneration. The realisation has been made that economic growth can be allied to environmental policy goals via a bioeconomy.

2. There are different definitions of what a bioeconomy is and it is not the aim of this report to produce a definitive definition. Consistent with the OECD 2009 publication, a working definition for the purposes of this report could be the set of economic activities in which biotechnology contributes centrally to primary production and industry, especially where the advanced life sciences are applied to the conversion of biomass into materials, chemicals and fuels. Nevertheless, it is realised that now the bioeconomy has grown way beyond biotechnology, and policy must reflect this. It is in fact embedded in the far-reaching transitions that are taking place in energy, transport and industrial production.

3. Adoption of this policy goal is high across the world. At least fifty nations (Figure 1), including the G7, have adopted the bioeconomy in their economic and innovation strategies (El-Chichakli et al., 2016). Some have dedicated bioeconomy strategies e.g. Finland, Germany, Japan, Malaysia, South Africa, the US and the West Nordic Countries; and others plan to include it in their own ones e.g. Austria, France, Iceland, Norway, Tunisia. Other countries have policies consistent with the development of a bioeconomy e.g. Australia, Brazil, China, India, Ireland, Korea, Netherlands, Russia, Sweden. A comprehensive roundup of different national intentions is given in Bioökonomierat (2015). Countries differ in their priorities, some focussing more on health, others on bioenergy. Many express the intention to develop a bio-based industry with higher added value products than biofuels or bioenergy.

**Figure 1   How the world is gravitating towards bioeconomy policy**


*Source*: adapted from http://biooekonomierat.de/biooekonomie/international/ . Since then, France, Italy, Norway and the UK (at least) are working on their dedicated bioeconomy strategies.

4. The transition to an energy and materials production regime based on renewable resources is expected to be fraught with many setbacks and obstacles, technically and politically. The earlier transitions from wood to coal and then from coal to oil were not complicated by the grand challenges faced today. Bennett and Pearson (2009) argued that the transition from coal-based to petrochemical feedstocks in the UK occurred between 1921 and 1967. However, they pointed out that there was no inevitability about the transformation. It was hastened by mass production of cars in the US in the 1920s. More-or-less by the end of the 1940s, a large supply of olefins was available in the US for the transformation to petrochemicals. Diffusion east took time, but by the late 1960s the UK organic chemical production industry was totally transformed to petrochemistry.

5. There is at least one lesson for bioeconomy policy makers to take from this: the transformation to a bioeconomy is going to take time. The current energy transition is at least two decades old already and is proving expensive: the cost of *Energiewende*is expected to top EUR 1 trillion. The world's population is continuing to rise whilst stagnating or falling in most of the OECD countries. Most importantly, the global middle class could increase to 4.9 billion by 2030, with 85% of the growth coming from Asia (OECD, 2010a). With middle class status comes consumption, but also emissions.

6. For bioeconomy policy makers, the future is complex and multi-faceted. The issues start in regions but have a global reach. As the first generation of bioeconomy policies comes to a close they have demonstrated that this vision of a bioeconomy pitched against grand challenges will not be easily realised without better national and international policies. This paper will address policy issues systematically across global, national and regional scales, and where these intersect and interact. It will use a familiar innovation framework to present these ideas, but will adapt the framework to the specific exigencies of the bioeconomy, illustrated by international examples of policy actions.

***Bioeconomy and the goal of replacing the oil barrel***

7. For many bioeconomy strategies across the world, a key aim is shared with the climate agreement reached in Paris in 2015, namely the desire to reduce the carbon pollution that threatens the planet, and creating more jobs and economic growth driven by low-carbon investments (UN FCCC, 2015). Historically, when a country doubles its GDP, its emissions rise by about 80% (UNEP, 2010). Multiple studies published in peer-reviewed scientific journals (Cook et al., 2016) show that 97% or more of actively publishing climate scientists agree: climate-warming trends over the past century are due to human activities. At the heart of the challenge is the need to decouple economic growth from environmental degradation, in particular the need to drastically cut emissions (OECD, 2009). The G7 has called for as-close-as-possible to a 70% reduction on 2010 emissions by 2050 (G7 Germany, 2015), and the Paris COP21 meeting reached a historical agreement on emission reductions. Ratification of the Paris Agreement by both China and the United States on September 03, 2016 was a huge step towards full ratification. On 05 October 2016, the threshold for entry into force of the Paris Agreement was achieved as 97 Parties had ratified of the 197 Parties to the Convention. The Paris Agreement subsequently entered into force on 04 November 2016[1].

8. Independence from price fluctuations of fossil-based resources is another major rationale for moving towards a bioeconomy. Price volatility has been a feature of crude oil for virtually all of its history, with serious social consequences and contributions to global economic recessions (Hamilton, 2011).

9. The bioeconomy could also alleviate concerns about the depletion of fossil-based resources. At the start of mass production, all of the major oil reserves remained to be found. At the start of the bioeconomy period, fewer new reserves were being added year-on-year. Conventional oil reserves have been in decline since 1980 (Owen et al., 2010). Discoveries of new oil reserves have dropped to their lowest level for more than 60 years (Bloomberg, 2016). For governments and the private sector alike, it is worth reiterating here that resource depletion affects many of the grand challenges. It is now necessary to see the opportunities of resource depletion rather than just the threats, an opportunity that has been estimated at USD 80 trillion by 2050 (Cayuela, 2013).

10. But ultimately what is meant by the transition to a low-carbon economy and building the bioeconomy is not seeing grand challenges as an insurmountable economic problem, but a chance to rebuild industry and society in a sustainable manner, bringing jobs and value-added through the exploitation of biomass rather than fossil resources. This has been explained as *a vision of the future* in the US because "*the core petroleum-based feedstock is a limited resource and diversification of feedstocks will provide even greater opportunity for the chemical manufacturing industry*" (National Academy of Sciences, 2015).

***Sustainability not a given***

11. The sustainability of bioeconomies, however, is not a given. If bioeconomies present potential solutions to the problems of oil and growth, they are also confronted with major challenges. One major problem confronting the realisation of a sustainable bioeconomy lies in reconciling the conflicting needs of agriculture and industry (Bosch et al., 2015). Inevitably food has to come first (e.g. SCAR, 2015; El-Chichakli et al., 2016), and the extent to which industrial production can rely on biomass is as yet undetermined (Kim et al., 2011; PBL Netherlands Environmental Assessment Agency, 2012). It can be argued that past energy and production transitions were able to flourish through "*more from more*". The bioeconomy may well have to flourish through "*more from less*". All bioeconomy aspirations depend on supplies of sustainable biomass (Piotrowski et al., 2015). In the post-fossil fuel world, an increasing

[1] http://unfccc.int/paris_agreement/items/9444.php

proportion of chemicals, plastics, textiles, fuels and electricity will have to come from biomass, which creates greater competition for land (Haberl, 2015). By 2050, the world will need to produce 50–70% more food (UN FAO, 2009), increasingly under drought conditions (Cook et al., 2015) and on poor soils (Karlen and Rice, 2015; Nkonya et al., 2016).

12. Another conundrum to consider is the sustainability of bio-based products, including biofuels and bioenergy. It has been shown that all biofuels are not equal in this regard, and the same applies to other bio-based products. Whilst there is evidence amassing (e.g. Hermann et al., 2011; Weiss et al., 2012) that bio-based products can offer environmental advantages, such as significant savings on GHG emissions) this cannot be assumed. Each needs to be treated on a case-by-case basis. However, there is huge variability in estimates of the environmental impacts of bio-based production, which is a serious impediment. International standardisation is required for the credibility of the industry. Serious misgivings concerning the use of life cycle analysis (LCA) as the sole tool in environment impact assessment have been raised (ANEC, 2012).

13. For these reasons, innovation and governance will be key. First, managing the transition towards a bioeconomy largely will hinge on the development and deployment of advanced integrated biorefineries that can utilise agricultural residues and food waste streams and could have lower carbon footprints (e.g. Iles and Martin, 2013; Kleinschmit et al., 2014). The International Energy Agency (IEA Bioenergy Task 42 Biorefinery, 2009) described a biorefinery as "*the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, chemicals) and energy (fuels, power, heat)*". This definition suggests that biorefineries should produce both non-energetic and energetic outlets and applies to product-driven biorefinery processes. Both primary products and energy-driven processes are considered as true biorefinery approaches provided that the final goal is the sustainable processing of biomass (de Jong and Jungmeier, 2015). One of the visions for the bioeconomy, that of distributed manufacturing in small- and medium-scale integrated biorefineries, does not correspond to the current reality of massive fossil fuel and petrochemical economies of scale, in many cases still supported by large fossil fuel consumption subsidies. Second, there will have to be greater effort in the development of sustainability standards for biomass and bio-based products, and there must be ways for these standards to be assured and enforced.

**Towards a Policy Framework for Bioeconomy**

14. While national bioeconomy strategies demonstrate intent and commitment, they tend to be short on policy detail. For this reason, it is instructive to look at the major policy implications of a bioeconomy in a single document, whether a framework is feasible or not. The magnitude of the task makes it difficult to create a policy framework as policy transcends a large range of policy families: tax, innovation, industry, agriculture, waste and trade immediately spring to mind.

15. Before looking at specific policy measures in the bioeconomy, it is worth reflecting on what would be found in a more general innovation strategy. Every country may approach fostering innovation in public policy differently, but OECD analysis suggests that innovation thrives in an environment characterised by some common features (Box 1). Bioeconomy policy should have all of these features, but there will be more as characteristics of a bioeconomy go beyond innovation policy. As will be evident from this paper, governments must look critically at these interactions in different policy families.

**Box 1 A toolbox of broad innovation policy**

- A **skilled workforce** that can generate new ideas and technologies, bring them to the market, and implement them in the workplace, and that is able to adapt to technological and structural changes across society.
- A **sound business environment** that encourages investment in technology and in knowledge-based capital, that enables innovative firms to experiment with new ideas, technologies and business models, and that helps them to grow, increase their market share and reach scale.
- A **strong and efficient system for knowledge creation and diffusion** that invests in the systematic pursuit of fundamental knowledge, and that diffuses this knowledge throughout society through a range of mechanisms, including human resources, technology transfer and the establishment of knowledge markets.
- Policies that **encourage innovation and entrepreneurial activity**. More specific innovation policies are often needed to tackle a range of barriers to innovation. Many of these actions include policies at the regional or local level. Moreover, well-informed, engaged and skilled consumers are increasingly important for innovation.
- A strong focus on **governance and implementation**. The impact of policies for innovation depends heavily on their governance and implementation, including the trust in government action and the commitment to learn from experience.

From this broad toolbox, the OECD identified five priorities that together constitute the basis for an approach to innovation:

1. **Strengthen investment in innovation and foster business dynamism**. Governments need to develop better policies to support investment in knowledge-based capital. They also should foster the growth of young and innovative small and medium-sized enterprises.
2. **Invest in, and shape, an efficient system of knowledge creation and diffusion**. Investment in long-term basic research remains a key priority; most of the key technologies in use today have their roots in public research.
3. **Seize the benefits of the digital economy**. Digital technologies continue to offer a large potential for innovation and growth.
4. **Foster talent and skills and optimise their use**. Skills are a key challenge for innovation, with two out of three workers not having the skills to succeed in a technology-rich innovation environment.
5. **Improve the governance and implementation of policies for innovation**. The impact of good innovation strategies depends on their governance and implementation, including the trust in government action and the commitment to learn from experience.

*Source*: OECD (2015b).

16. The reader is encouraged to move back and forth from the specifics of recommended bioeconomy policy to Box 1, which can be regarded as a check list of good innovation policy. However, it is also necessary to recognise where bioeconomy policy touches on other areas of policy.

### *Supply-side, demand-side and cross cutting measures*

17. However, there are several critical policy areas, many of them under innovation policy that can be readily identified. Carus (2014) identified the core of these, and some others can be found in Table 1 grouped under three essential categories, which can roughly be translated to supply-side, demand-side and

a mixture of both supply and demand-side policies (i.e. cross-cutting measures). This is consistent with the view that both supply- and demand-side policies are needed for effective innovation.

**Table 1. Policy inputs for a bioeconomy framework**

| Feedstock/Technology push | Market pull | Cross-cutting |
|---|---|---|
| Local access to feedstock | Targets and quotas | Standards and norms |
| International access to feedstock | Mandates and bans | Certification |
| R&D subsidies | Public procurement | Skills and education |
| Pilot and demonstrator support | Labels and raising awareness | Regional clusters |
| Flagship financial support | Direct financial support for bio-based products | Public acceptance |
| Tax incentives for R&D | Tax incentives for bio-based products | Investment in knowledge-based capital |
| Improved investment conditions | Incentives related to GHG emissions (e.g. ETS) | |
| Technology clusters | Taxes on fossil carbon | |
| Governance and regulation | Removing fossil fuel subsidies | |

*Source:* Adapted from Carus (2014)

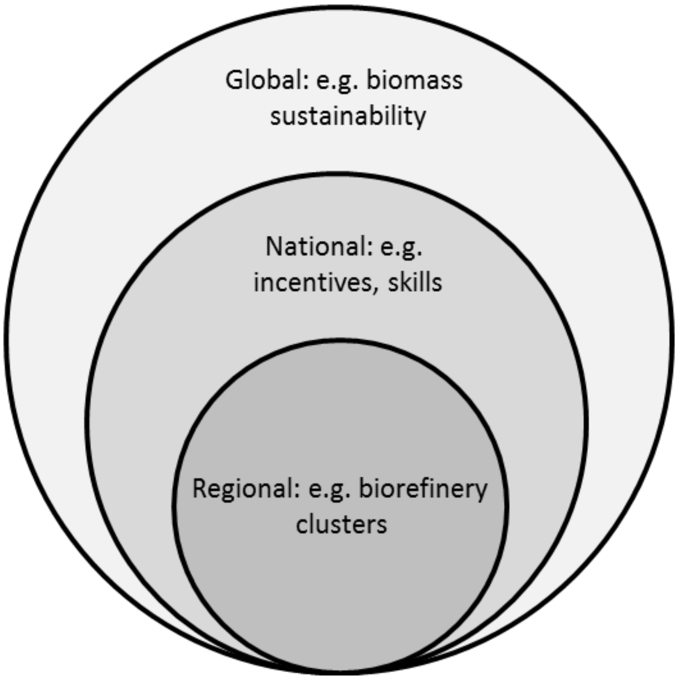
18. Demand is a major potential driver of innovation, yet the critical role of demand as a key driver of innovation is not universally recognised in government policy (Edler and Georghiou, 2007). Historically, OECD governments have tended to rely on macroeconomic policies (e.g. monetary and fiscal policy) and framework conditions (e.g. competition, tax or entrepreneurship policies) to support market demand and avoid distortion. In recent years, however, OECD countries and emerging economies such as Brazil and China have used more targeted demand-side innovation policies. These include measures such as public procurement, regulation, standards, consumer policies, user-led innovation initiatives and lead market initiatives to address market and system failures in areas in which social needs are pressing (OECD, 2011a).

19. Moreover, experience in OECD member countries has shown that the use of such demand-side policies remains limited to areas in which societal needs are not met by market mechanisms alone (e.g. environment) or in which private and public markets intersect (e.g. energy supply). Bioeconomy policy goals are both environmentally and energy-driven. This focus on the demand side also reflects a general perception that traditional supply-side policies – despite refinements in their design over recent decades – have not been able to bring innovation performance and productivity to desired levels.

***Policy at multiple scales***

20. A dimension of bioeconomy policy that makes it so complex is the multiple scales of action required (Figure 2). These range from regional development, e.g. biorefinery deployment; through national R&D, e.g. synthetic biology, IT convergence and automation; to the global issues of biomass and its sustainability. The distributed bioeconomy manufacturing model calls for a 'glocal' approach i.e. both global and local. It stresses the proximity both of the sites where raw material is acquired, and where goods and energy are produced and consumed (McCormick and Kautto, 2013). The success of this model is not based on economies of scale, which will remain a great challenge as the petrochemicals model increasingly is based on this (IHS Markit, 2015).

**Figure 2. Bioeconomy policy must operate across scales**




21. Furthermore, one of the greatest challenges for a bioeconomy is that the relevant sectors exist in silos and do not necessarily communicate with each other. This can be equally true of the policy families. What follows is a summary of policy issues discussed in three OECD papers of the biennium 2015-2016 based on bioeconomy. It is not a reiteration of those policy issues. Rather, it is an ordering of policy measures into a potential 'framework' for a bioeconomy of regional, national and global reach. Evidence for the need for such a policy framework is provided in the form of examples from OECD and non-OECD nations.

## FEEDSTOCK/TECHNOLOGY PUSH (SUPPLY-SIDE)

### Local access to feedstocks: Supply and value chains in the distributed manufacturing model

22. There are several policy advantages to making use of local feedstocks that are currently attractive to policy makers. Firstly, using local feedstocks is typically more sustainable than transporting them from further afield or abroad in terms of energy consumed in the transportation. Secondly, creating local and rural jobs has obvious merits for policy. It also aligns with broader policy goals such as smart specialisation, knowledge-driven reindustrialisation, sustainable development and the circular economy. Nevertheless, there are major challenges ahead.

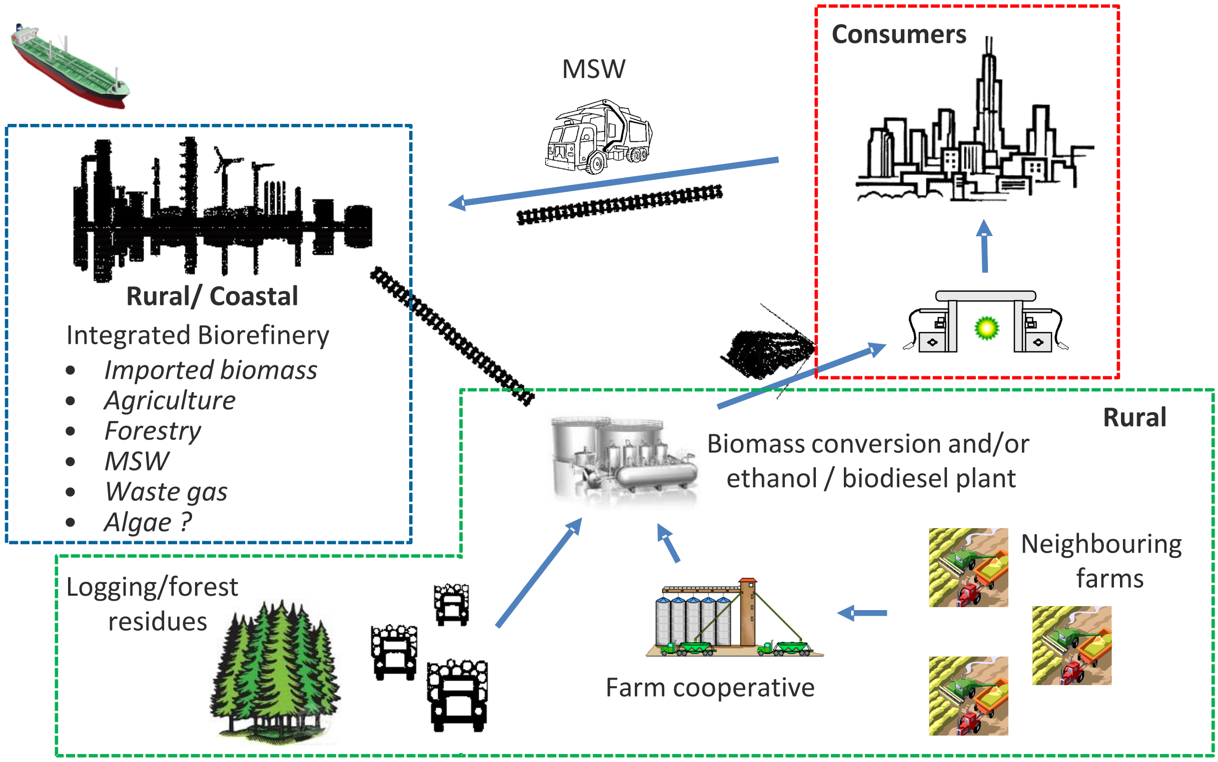
23. One of the challenges is the complexity of biorefinery value chains (Figure 3). The distributed manufacturing 'glocal' model means establishing many interconnected local production plants that are integrated with other nearby industries to ensure that residues and wastes are fully utilised in different processes (Luoma et al., 2011). What the diagramme does not show is the involvement of research organisations and chemistry/biotechnology small-medium enterprises (SMEs), or end-of-life strategies e.g. composting. Neither does it illustrate the cascading use of the biomass concept. Nevertheless, it does illustrate the complexity of actors involved. In Finland for example, the average forest size is 30 hectares, and there are hundreds of thousands of forest owners. The biorefinery at Bazancourt-Pomacle in France (Schieb and Philp, 2014) involves ten thousand farmers. Figure 3 also takes account of the possibility of involving international value chains (imported biomass).

24. Government programmes are promoting research and development across supply and value chains, but supply markets receive little attention (Knight et al., 2015). This creates one of the conditions that deter investors. This lack of attention to supply markets possibly reflects reluctance by governments to be seen to be intervening in markets and could also involve potentially contravening anti-competitive practices (Institute of Risk Management and Competition and Markets Authority, 2014).

25. The stakeholders concerned are so different that they would never come into regular contact with each other in the fossil-based economy. However, to make biorefining economically sustainable, they need to be connected. There are roles to be played by policy makers to prevent this communication process from being random, ad-hoc and inefficient. Analysis points, for example, to the potential importance of buyer cooperatives and other forms of supply market intermediaries (Knight et al., 2015).

26. This is consistent with the activities of publically funded regional clusters in industrial biotechnology becoming involved with supply and value chains (Kircher, 2012). Regional clusters are well positioned to evaluate regional options, to build capacity in the regions, and then to look beyond the regions. Building capacity at the local level depends on quality local business networks e.g. agricultural and forestry machine rings and relationships of trust. Building beyond the clusters can exploit the expertise gained at regional level to expand and join up with other regions.

**Figure 3. The generalised supply and value chains of biorefining**




27. Encouraging software design to improve decision making would be a relatively low-cost public sector intervention. For example, a database developed by Black et al. (2016) for the assessment of biomass supply chains for biorefinery development covers origin, logistics, technical and policy aspects. This is assuming greater importance as the need to establish bespoke biomass supply chains is becoming a reality. Industrial developers will face many business-critical decisions on the sourcing of biomass and the location of biorefineries. Software of this type could simplify decision making. It could be developed in an open-source manner with regional clusters to make it sufficiently bespoke.

***Innovative approaches: Japan and Brazil***

28. The Biomass Nippon Strategy (2002) was one of the earliest approaches to accessing local access to feedstocks by coordinated action of three Japanese ministries: the Ministry of Agriculture, Forestry & Fisheries, Ministry of the Environment, and the Ministry of Economy, Trade and Industry. The strategy consists of three parts: background, goals and basic strategies. Concerning the background, four reasons are identified, including a necessity to create a "*recycling-oriented society*". The strategy sets three types of goals: technical, regional and national. The basic strategies include those for production, collection and transportation, conversion technologies, and stimulation of demand for energy use or material use. The marketable opportunities for biomass technologies have been strengthened by its wide acceptance[2].

29. The 'biomass town' is an area where a comprehensive biomass utilisation system is established and operated through the cooperation of various stakeholders in the area. Each step from biomass generation, conversion, distribution and use is linked together among the stakeholders, and their biomass utilisation is stable and appropriate to the community in the area.

2 http://www.iea.org/policiesandmeasures/pams/japan/name-23185-en.php

30. The 'biomass town plan' is a planning document that describes the target area characteristics, implementing bodies, goals and effects, procedure of developing the plan, biomass potential, and biomass utilisation, all of which eventually contribute to building consensus among various stakeholders to formulate the biomass town. Local governments lead the development and implementation of the plans to realise biomass towns. Approximately 300 biomass town plans have been developed to date since 2005 in Japan. The Ministry of Agriculture, Forestry & Fisheries (MAFF) has supported forming biomass town plans in four pilot areas of four ASEAN countries (Indonesia, Malaysia, Thailand and Vietnam).

31. In 2009, the Brazilian government launched the Agro-ecological Zoning for Sugarcane initiative (*Zoneamento Agroecológico da Cana-de Açúcar*[3]) to promote the expansion of sugarcane production in areas that are agronomically, climatically and environmentally suitable. This initiative is considered essential to guarantee the sustainable growth of sugarcane production. The underpinning rules established by Agro-ecological Zoning include:

- No sugarcane expansion or new ethanol production facilities in sensitive ecosystems like the Amazon, the Pantanal wetlands and Upper Paraguay river basin;
- No clearance of native plants to expand sugarcane cultivation anywhere in the country;
- Identification of suitable areas where sugarcane should be prioritised. These areas include land with proper conditions for the use of mechanical harvesting, cattle breeding areas that are underused or degraded (more than 34 million hectares), and also regions with lower need for water usage in production.

**International access to feedstocks: Biomass potential and sustainability**

32. Large quantities of biomass are already being shipped around the globe, with most of it destined for OECD countries (BP-EBI, 2014). Clearly the use of biomass globally is increasing and is going to increase further in future (e.g. Klein et al., 2014; Schmitz et al., 2014). Biomass potential and its cost could become crucial factors that affect overall climate change mitigation costs (Rose, 2013). It is also recognised at the international level that production of biomass can have major negative impacts on the environment and that there is a need to address this issue in policy and business (Knudsen et al., 2015).

33. The stark reality of the current situation regarding biomass sustainability can be summed up succinctly. 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. That should make governments uncomfortable about the future. The metrics for biofuels sustainability are still non-binding on biomass.

***Need for metrics of biomass sustainability and potential***

34. Biomass potential refers to how much biomass can be grown. The sustainability of biomass potential is a linchpin of bioeconomy policy: if biomass cannot be grown and harvested sustainability then negative environmental impacts are inevitable e.g. over-exploitation, soil erosion, deforestation. Seidenberger et al. (2008) have attempted to compile global biomass potential ranges from 18 different studies, and noted huge variability in the results. Estimating the technical potential of biomass production over the transition pathways of the Intergovernmental Panel on Climate Change (IPCC)'s fifth assessment

3 https://www.embrapa.br/en/busca-de-produtos-processos-e-servicos/-/produto-servico/1249/zoneamento-agroecologico-da-cana-de-acucar

report leads to a range of 10 to 245 EJ[4] per year primary energy from biomass by 2050 (IPCC, 2014). Overall in the literature, Schueler et al. (2016) observed a range of technically available potentials between 50 and 500 EJ per year by mid-century. Applying sustainability criteria to the available biomass potential decreases it considerably.

35. The variations in range can be attributed to several reasons: different objectives over different time frames (most biomass potential studies have future estimates until 2050); variety of methodologies and approaches; the lack of a commonly agreed definition on the types of biomass (forest residues, harvest and process residues); treating various categories of land differently; different data sets and scenario assumptions; assumptions on future land productivity, studies lacking transparency and omission of key factors, and; geographical scope.

36. There has been a concerted effort of over a decade in the US to discover the national biomass potential, resulting in the first '*Billion Ton Report'*, completed in 2005 (USDOE, 2005), with updates in 2011 and 2016 (USDOE, 2011; USDOE 2016). The basics remain the same throughout these reports: that the US, depending on assumptions made, may be able to produce one billion tons of dry biomass per annum, thus substituting 30% of gasoline requirements with renewable biofuels. The authors estimate that the US currently uses 365 million dry tons of agricultural crops, forestry resources, and waste to generate biofuels, renewable chemicals, and other bio-based materials. There will be a follow-up paper that evaluates policies and economic conditions needed to direct investment to the bio-based economy and to build the biorefineries that will utilise potential biomass resources (Erickson, 2016).

*No internationally agreed tools or indicators for biomass sustainability*

37. A frequently discussed tool for measuring biomass sustainability is life cycle analysis (LCA). However, it only takes account of environmental performance, and not of economic or social factors. Moreover, significant data gaps exist in the availability of life cycle inventory data (Grabowski et al., 2015). When other sustainability tools are applied, they fail to meet fundamental scientific requirements for index formation: normalisation, weighting, and aggregation (Böhringer and Jochem, 2007). So currently no one assessment tool fits the needs of biomass sustainability.

38. And there is also no international agreement on what criteria should be used. International harmonisation requires not only robust analysis, but consensus, and the latter is often more difficult to achieve. Social criteria are sometimes regarded as low in reliability and practicability as they are difficult to measure. As a result, they tend to be assigned a low ranking (van Dam and Junginger, 2011). But they may have strong bearing on true sustainability e.g. workers' rights, land rights (Shawki, 2016).

39. The major limitation of the vast majority of methods is their inability to aggregate the different sustainability issues into a single measure in an objective way (Gaitán-Cremaschi et al., 2015). Aggregation requires making complicated trade-offs between sustainability aspects with other factors that are not necessarily intuitive. Currently, practitioners can only generate an overall sustainability number by using their own weighting factors when aggregating the different impact categories and this introduces subjectivity.

***International harmonisation and a level playing field for biomass sustainability***

40. International harmonisation regarding approaches to biomass sustainability assessment is needed. Current biomass sustainability assessments are a patchwork of voluntary standards and regulations with a lack of comparability. In a survey of eleven European countries (Knudsen et al., 2015), the majority (eight)

4 1 exajoule = $10^{18}$ joules. The joule (J) is the SI unit of energy and work.

of those countries saw the need for a more consistent and standardised approach to sustainability criteria across the different fields of the bioeconomy. This need covers widely different criteria and indicators, voluntary schemes as well as EU-level approaches. The general arguments for the need for a uniform approach to sustainability criteria are: to increase transparency; to avoid market distortions, and; to enable comparisons across countries.

41. Most of the biomass being shipped internationally is for bioenergy purposes, and there is a risk that an unbalanced attention to only one part of the bioeconomy and only the energy transition, will distort the playing field even further. Different fields of the bioeconomy are expected to interact. For example, the cascading use of biomass (Odegard et al., 2012; Keegan et al., 2013) envisages the same biomass in use for high value and low value chemicals and materials, biofuels and bioenergy. There is a need to create a common, level playing field for all sustainable biomass uses (Carus et al., 2014). This is vital for the economic operation of integrated biorefineries.

***Biomass disputes and their settlement***

42. Biomass disputes have already occurred internationally, and these can be expected to increase in number in the absence of biomass sustainability assessment and certification that is agreed by importing and exporting nations.

43. A dispute arose in 2012 between an international environmental organisation and an energy company wishing to ship large quantities of wood pellets to Europe that had originated from Canadian primary forest infested with the mountain pine beetle. These sources of biomass represent the largest potential for further development of the bioenergy industry in Canada by far - the area affected by natural disturbances such as insect infestations and wildfire is much larger than the total area of logging.

44. However, this represents forest that has had minimal human intervention, and therefore would be excluded from importation into the European Union as it would be termed “primary forest” i.e. is in a “natural condition”, in that it has not been harvested before and regrown (Lamers et al., 2014). This would, of course, create higher (policy) costs. The operational reality in Canadian forests clashed with policy prescriptions in the EU.

45. Much less trivial was an event of August 2015, when four large groups of Asian companies were excluded from the Norwegian sovereign wealth fund over instances of deforestation in Indonesia associated with palm oil (*Financial Times*, 2015). The oil palm is a crop at the front line of the bioeconomy and its sustainability. Many of the economic, social and environmental concerns that are defining concerns for a bioeconomy are seen with this crop. In all four cases, Norges Bank’s executive board decided there were “*no other options open*” for dispute settlement. A policy option might be the creation of an international biomass dispute settlement facility (The Hague Institute for Global Justice, 2012). Biomass disputes relate to human rights issues (land rights, worker’s rights), environmental issues (effects on soil, land, air, biodiversity and climate) and economic issues (international trade, market distortions, property rights, business-to-business conflicts).

***Monitoring and enforcement***

46. Forest over-exploitation, product forgery and misidentifications are common risks in the forest industry. The risks will grow as the bioeconomy grows. It is estimated that illegal logging accounts for 50-90% of all forestry activities in key producer tropical forests, such as those of the Amazon Basin, Central Africa and Southeast Asia, and accounts for 15-30% of all wood traded globally (Nellemann, 2012). The trade in illegally harvested timber is estimated to be worth between USD 30 and USD 100 billion annually, or 10–30% of global wood trade.

47. Therefore, an accurate, universal, stable and specific method allowing non-specialists to identify the source species from a tiny amount of tissue is needed (Laiou et al., 2013). The combination of satellite monitoring of illegal logging (Lynch et al., 2013) and DNA barcode verification could become potent tools in law enforcement in a forest bioeconomy. Moreover, DNA barcoding may come to be routinely used in assessing biodiversity. Meta-barcoding technology can characterise the species compositions of mass samples of environmental DNA. Compared with standard biodiversity data sets, meta-barcoded samples are taxonomically more comprehensive, many times quicker to produce, less reliant on taxonomic expertise and auditable by third parties, which is essential for dispute resolution (Ji et al., 2013). Therefore this offers a reliable, cost-effective way of producing biodiversity information for policy makers (European Commission, 2015b).

**The role of R&D**

48. The central biotechnology for bio-based materials production is metabolic engineering. It still takes 50-300 person years and many millions of dollars to bring a metabolically engineered product to the market (Hong and Nielsen, 2012). Chemistry is way ahead in success rates. There are over 30 bio-based chemicals at TRL 8[5] or above (European Commission, 2015c), but few of them from biotechnology. However, there is emerging evidence that success rates would be higher if there were more R&D for convergence – of industrial biotechnology with green chemistry (e.g. Dusselier et al., 2015; Philp et al., 2013), and a higher level of systems integration through IT/computation convergence with synthetic biology and metabolic engineering (e.g. Rogers and Church, 2016). In this context government R&D subsidies might be considered.

***The bottlenecks in bio-production***

49. The commercial successes in metabolic engineering are dwarfed by the research successes. Therefore for governments this could look like a poor return on investment. Korea is a nation with an advanced capability in metabolic engineering. In response to the lack of commercial success, researchers at the Korea Advanced Institute of Science and Technology (KAIST) have recently suggested ten general strategies of systems metabolic engineering to successfully develop industrial microbial strains (Lee and Kim, 2015). Systems metabolic engineering differs from conventional metabolic engineering by incorporating traditional metabolic engineering approaches along with tools of other fields, such as systems biology, synthetic biology, and molecular evolution. What is evident is that there are many groups competent in one or more of these specialisms, but very few companies that integrate them all into a production process. There is a clear need for better collaboration between academia and industrial biotechnology companies (Pronk et al., 2015), and far more rapid transfer of knowledge between the public and private sectors.

50. At a more detailed level, the literature reveals several biotechnologies that need to be further developed to improve the translation from the laboratory to the market. The following list may not be exhaustive, but each item recurs frequently.

- **Biomass pre-treatment and consolidated bioprocessing (CBP)**. The US Department of Energy endorsed the view that CBP technology is widely considered the ultimate low-cost configuration for cellulose hydrolysis and fermentation (USDOE, 2006). There have been research successes (e.g. Salamanca-Cardona et al., 2016), but as yet no viable commercial process.

5 Technology Readiness Level (TRL) 8, on a scale from 1-9, translates roughly to almost ready for commercial deployment.

- **Growth on C1[6] compounds**. Progress has been slow because bacteria known to use C1 substrates can be difficult to work with in an industrial setting, and many have limited genetic tools. Introduction of carbon utilisation pathways from such strains into a tractable production strain also presents significant challenges (Burk and Van Dien, 2016).

- **Computational enzyme design**. Current approaches for engineering enzymes for improved activity and specificity are semi-rational at best. Although the field is still in its infancy, computational enzyme design has the potential to facilitate rational protein engineering or even design completely novel functions (Privett et al., 2012; Barton et al., 2015).

- **Minimal cells for bio-contained microbial factories**. The start point for designing future production strains will be minimal, or chassis cells, self-replicating minimal machines that can be tailored for the production of specific chemicals or fuels (Ostrov et al., 2016) and that meet standards for biocontainment and safety (Mandell et al., 2015).

- **Robustness**. Natural microorganisms were not intended for the 'extreme' conditions of industrial production, and new characteristics to make them more robust have to be engineered in (Zhu et al., 2011). So pervasive is the issue that DARPA (US) has a research priority dedicated to it (the Biological Robustness in Complex Settings (BRICS)[7] portfolio).

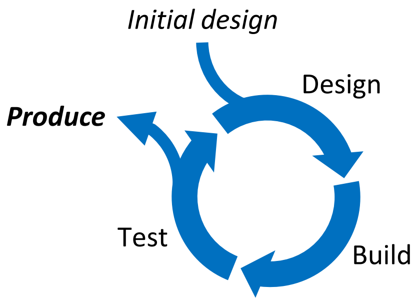
- **Productivity**. Most natural microbial processes are incompatible with an industrial process as productivity is often too low to be scalable (e.g. Harder et al., 2016). Engineering cell metabolism for bio-production produces inefficiencies in the cell (Wu et al., 2016).

- **Gene and genome editing in production strains**. Efficient methods enabling multiplex genome editing are urgently needed (Esvelt and Wang, 2013). Settling of the patent issues around CRISPR/Cas9 (Ledford, 2016) would be helpful as the technology lends itself to traditional production strains (e.g. Jiang et al., 2015; Stovicek et al., 2015) but also to non-conventional strains (Nymark et al., 2016).

***Support IT/computation convergence in bio-production***

51. When the engineering cycle (Figure 4) is applied to biotechnology, failure is common. There is a need for biotechnology to have its own high-level programming language(s) and software to transform the engineering cycle (Sadowski et al., 2016).

**Figure 4. The engineering design cycle**




6 Any organic compound that consists of a single carbon atom with attached hydrogen atom(s)

7 http://www.darpa.mil/program/biological-robustness-in-complex-settings

52. Many variants exist, but this shows the basic elements of engineering design through a phase of initial design, building and testing of a part/system/device. Nobody expects an optimal design at the first attempt. Therefore the process is iterated as often as necessary to meet the engineering specifications.

*The test phase is a major bottleneck in the metabolic engineering design cycle*

53. Phenotype evaluation is a major rate-limiting step in metabolic engineering (Wang et al., 2014). Because the price of DNA synthesis has plummeted in the last two years, the design and build stages can create perhaps a billion designs per day. When constructing production strains for biofuels or bio-based chemicals, design success will be measured in the amount of product formed, and this is the function of the test part of the cycle. Here the throughput is limited to hundreds of thousands of design evaluations per day. Improving this throughput by mechanical or electronic automation is going to be limited as the orders of magnitude of improvement needed are so high. The advances necessary have to come from biology itself, but will be vastly facilitated by the integration of computational tools. Individual research groups are constructing their own computational tools, but of course this does not lend itself to industry standardisation.

54. Therefore a new data analysis pipeline that simplifies the interrogation of phenotype-sequence relationships is urgently required. In the age of machine learning, ultimately the data should inform the next iteration of design without lumpen human intervention (Rogers and Church, 2016). For example, AutoBioCAD promises to design genetic circuits for *E. coli* with virtually no human user input (Rodrigo and Jaramillo, 2013). Thus algorithms are needed that incorporate machine learning to correlate data from different data sets for the purpose of linking genes, proteins, and pathways without *a priori* knowledge (Wurtzel and Kutchan, 2016).

**Production facility support: financing demonstration and full-scale biorefineries**

55. Biorefineries at demonstration scale are difficult to bankroll because the level of production is not high enough to influence a market. Full-scale biorefineries are also very difficult to build for various reasons, most relating to uncertainty – of technology, of supply and value chains and of policy. The private sector is unwilling to shoulder the entire financial burden, and this has necessitated public-private partnerships (PPPs) to de-risk private investments.

56. Building biorefineries needs the largest investments in the innovation chain for a bioeconomy (Figure 5). Public-private partnerships (PPPs) have been necessary to de-risk private investments. The most common form of financing for such technologies in the US is a hybrid of equity, teamed with either federal grants or a federally backed loan guarantees. This streamlines the approval steps and the control. To build biorefineries, both the USDA and USDOE have favoured 20-year loan guarantees. They were initially limited to biofuels projects, but for 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.

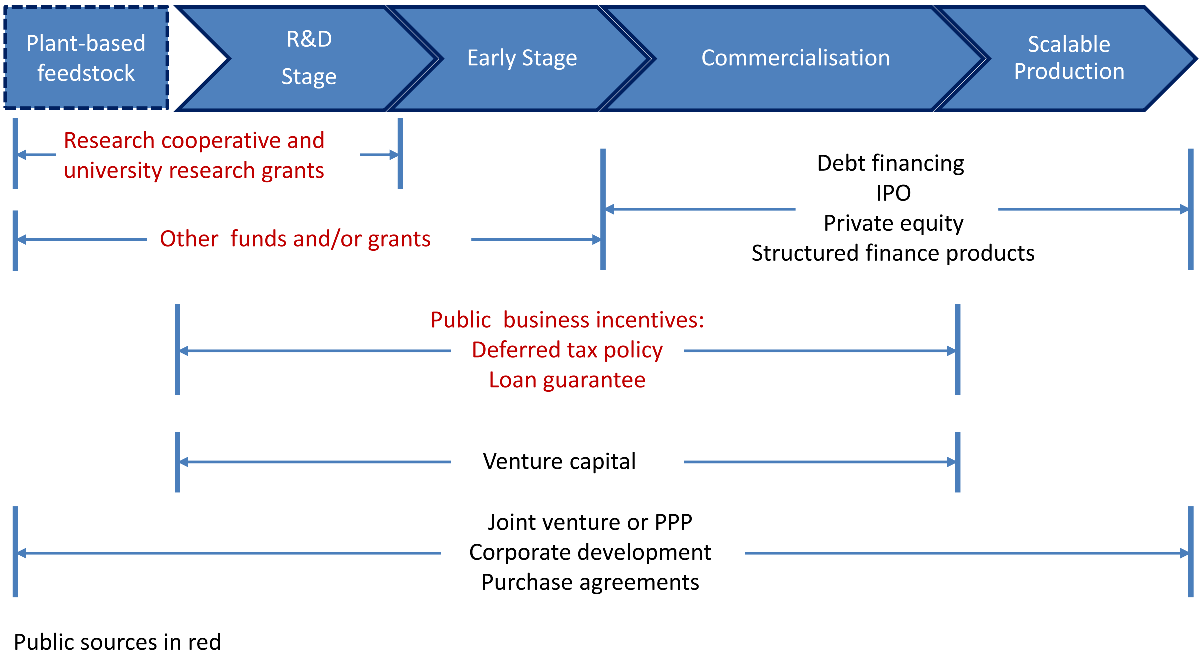
57. Loan guarantees have not been common in Europe, but are now becoming available through InnovFin. InnovFin consists of a series of integrated and complementary financing tools and advisory services offered by the European Investment Bank (EIB) Group, covering the entire value chain of research and innovation (R&I) in order to support investments from the smallest to the largest enterprise[8]. InnovFin aims to improve access to risk finance for research and innovation projects, research

8 http://www.eib.org/products/blending/innovfin/

infrastructures; public-private partnerships and special-purpose projects promoting first-of-a-kind, industrial demonstration projects (Scarlat et al., 2015). InnovFin will be much larger and broader in scope for the planning period 2014-2020. The EIB is able to finance a range of activities in the sector (Schlingmann, 2016):

- Investments by SMEs and MidCaps in capex, permanent working capital and RDI;
- Sector specific corporate R&D programmes (up 3- to 4- year programmes);
- Innovative prototypes and pilot plants;
- First-of-kind large-scale industrial production facilities for innovative processes and advanced manufacturing;
- Industrial production facilities promoted by bigger enterprises in cohesion areas or targeting specific EIB objectives.

**Figure 5. Funding mechanisms in industrial biotechnology**




*Source*: Adapted from Milken Institute (2013).

### *Demonstrator facilities*

58. The demonstrator phase is a critical phase on the road to commercialisation. Larger than pilot scale, economic and technical limitations often make themselves evident during demonstration. This saves expense rather than having to correct these limitations at the full-scale production phase.

59. The federal state of Saxony-Anhalt and the three Federal Ministries for Research, Agriculture and Environment have provided approximately EUR 50 million to build the Centre for Chemical-Biotechnological Processes (CBP) at Leuna. It is a facility of the Fraunhofer Society focused on up-scaling

of research from the laboratory to the pilot and demonstrator facility stages (Government of Germany, 2015).

60. In 2015 Global Bioenergies of France secured a EUR 4.4 million loan from a consortium of French banks to build a demonstrator plant at CBP[9]. The financing of the plant is also supported by a EUR 5.7 million subsidy from the German Ministry for Education and Research (BMBF). Global Bioenergies has maturing technology for the bio-production of iso-butene, and the demonstrator has been specifically designed for the bio-production of gaseous hydrocarbons.

***Bio-based Industries Joint Undertaking (BBI JU)***

61. The major bio-based PPP in Europe is the Bio-based Industries Joint Undertaking (BBI JU[10]). Other than biorefinery finance itself, the PPP focusses on supply chain development and the development of markets for bio-based products and the optimisation of policy frameworks. BBI JU will fund demonstration and flagship projects. For example, the flagship project FIRST2RUN is coordinated by Novamont (Italy) in partnership with four companies: SIP (UK), SoliQz (The Netherlands), Biophil (Slovakia), Matrìca, (Italy - JV 50:50 Novamont/Eni Versalis), with a university partner (The University of Bologna).

62. FIRST2RUN aims to demonstrate the technical, economic and environmental sustainability of an integrated biorefinery. Low input oilseeds such as thistle, cultivated on arid and/or marginal land, are used to extract vegetable oils to be converted into bio-monomers for the formulation of bio-products such as bio-lubricants, cosmetics, plasticisers and bio-plastics. Standardisation, certification and dissemination will be integral aspects of the project, as well as a study into the social impact of products deriving from renewable resources.

***Other instruments***

63. Other innovative instruments may become more important in future. Green Bonds enable capital-raising and investment for new and existing projects with environmental benefits. The Green Bond Principles[11] instrument is a mechanism to raise large capital sums, with the financing and management of project risks undertaken by the project sponsors, not the investors that might or might not have the capacity to manage said risks.

64. A government-backed green investment bank differs from a typical fund in that it should not just disburse government money, but as a ‘bank’ it should be able to raise its own finance, bring in banking expertise and offer a range of commercially-driven interventions - loans, equity and risk reduction finance. A green investment bank is a publicly capitalised entity established specifically to facilitate private investment into domestic low-carbon and climate-resilient infrastructure and other green sectors such as water and waste management. These dedicated green investment entities have been established at national level (Australia, Japan, Malaysia, Switzerland, United Kingdom), and at state and even city level (OECD, 2016b).

9 http://www.global-bioenergies.com/e4-4-million-loan-from-a-consortium-of-french-banks-start-of-construction-work-on-the-demonstrator-in-germany/?lang=en

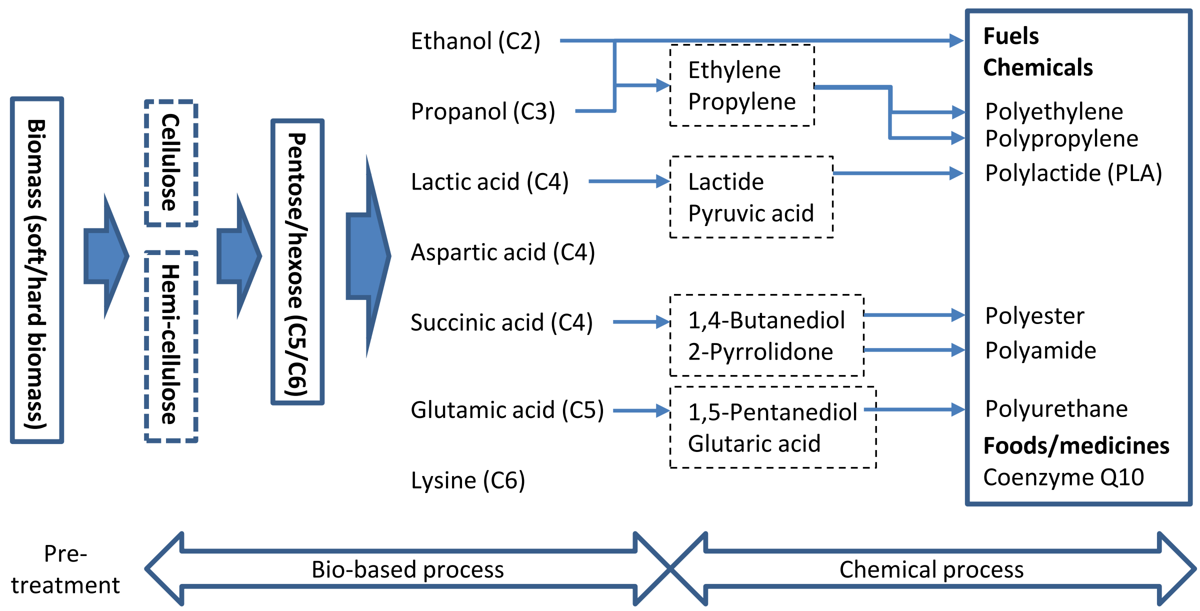
10 http://www.bbi-europe.eu/

11 http://www.icmagroup.org/Regulatory-Policy-and-Market-Practice/green-bonds/green-bond-principles/

***Governments should have a special focus on integrated biorefineries***

65. There is a distinct danger that many single-feedstock, single-product biorefineries are doomed in the absence of government support as they are at the mercy of market fluctuations beyond their control. Overcoming feedstock and product price volatility may be best accomplished by making a range of fuels and chemicals at the same facility (Figure 6). Such a biorefinery is obviously technically very complex, even more so than a petrochemical facility. The concept has become synonymous with the cellulosic biorefinery, of which there is a handful worldwide producing a trickle of cellulosic ethanol.

**Figure 6. Schematic representation of combined biological and chemical processes that might occur in an integrated biorefinery that makes fuels, chemicals and plastics of different added value**




66. But there are some advantages that should be considered compared to single-feedstock, single-product biorefineries that make this model particularly attractive. There is the ability to switch between feedstocks and products when, for example, one particular feedstock is too expensive. Switching between feedstocks also helps cope with seasonal availability (Giuliano et al., 2016). Integration avoids the low-margins trap of producing high volume fuels (OECD, 2014a), and there is less fractional market displacement required for cost-effective production of high-value co-products as a result of the economies of scale provided by the primary product (Lynd et al., 2005). The economies of scale provided by a full-size biorefinery lower the processing costs of low-volume, high-value co-products. Common process elements are involved, lowering the need for equipment duplication, with subsequent decreases in capital cost. Co-production can provide process integration benefits (e.g. meeting process energy requirements with electricity and steam co-generated from process residues).

67. A truly integrated biorefinery has yet to be built. The benefits notwithstanding, there are several defining challenges that are proving difficult to overcome (Cheali et al., 2015). These merit the focussed attention of policy makers.

- While integrating conversion platforms with downstream processes it is difficult to maximise efficiency.

- Accounting for a wide range of feedstock, processing paths and product portfolios (Tsakalova et al., 2015) is technically very demanding and costly.

- Formulating local/regional, decentralised solutions (i.e. local supply and value chains) instead of global solutions (as in petrochemistry) requires a great deal of policy attention to incentivise but not distort markets.

- If feedstocks are not available locally then the location of the biorefinery may be crucial, especially if feedstock is to be imported from overseas, indicating the need for a coastal and/or rural location.

68. All of this calls for close collaboration between the public and private sector. At the regional level the expertise may not be available in regional governments, and external experts would lack local knowledge. Therefore governance becomes a central consideration. When inward investment by another country is involved, this is especially important.

69. Chinese renewable energy investment company Kaidi[12] announced plans to build a biodiesel refinery in Finland in 2016. The value of the investment is EUR 1 billion, making it the biggest Chinese investment in Finland to date. The European Commission has decided to grant EUR 88.5 million to the project (*Helsinki Times*, 2016). The first of its kind, it will produce biofuels by using wood-based biomass, such as energy wood, harvesting remains and even leftover bark from the forest industry as the main feedstock. The plant will produce 200 000 tonnes of biofuel per year, of which 75% will be renewable diesel and 25% renewable gasoline.

**Tax incentives for industrial R&D**

70. Tax incentives reduce the marginal cost of R&D and innovation spending and they are usually more neutral than direct support. Over the past decade, OECD member countries have increasingly turned to tax incentives, (rather than grants or other direct forms of support), with increasing generosity, as a means to support investment in R&D (OECD, 2014c). The majority of OECD countries use such tax incentives, as do many of the BRICS economies.

71. However, as many bio-production companies are young, they may benefit less from R&D tax credits if they have not yet generated taxable income to make immediate use of (non-refundable) R&D tax incentives. This may inhibit innovation and growth as such firms have particular strengths as R&D performers and job creators unless measures such as cash refunds, carry-forwards, or the use of payroll withholding tax credits for R&D-related wages are used (OECD, 2015b).

72. Another aspect for governments to think about is the position of small domestic companies in bio-production in relation to MNEs, which are becoming increasingly attracted to bio-production. R&D tax incentives should be designed to meet the needs of these small firms that lack cross-border tax planning opportunities. Otherwise, they may be put at a competitive disadvantage in relation to MNEs unless other measures, such as ceilings and differentiated rates, are put in place to ensure a level playing field.

73. In the US, 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 112$^{th}$ Congress, with some measures reintroduced subsequently in the 113th Congress (Box 2).

[12] http://www.kaidi.fi/

**Box 2. US policy and tax measures to support bio-production**

- H.R. 3390, Qualifying Renewable Chemical Production or Investment Tax Credit Act of 2015 / S. 2271 Renewable Chemicals Act of 2015

Allows a producer to choose between a Production Tax Credit (PTC) or Investment Tax Credit (ITC). It promotes investment and domestic production for innovative renewable chemicals. The Qualifying Renewable Chemical Production or Investment Tax Credit Act of 2015 was introduced in the House of Representatives (https://www.congress.gov/bill/114th-congress/house-bill/3390/text); the Renewable Chemicals Act of 2015 was introduced in the Senate (https://www.congress.gov/bill/114th-congress/senate-bill/2271/text)

- Protecting Americans from Tax Hikes (PATH) Act

The Protecting Americans from Tax Hikes (PATH) Act made permanent the R&D tax credit, with modification for eligible small businesses (USD 50 million or less in gross receipts) to claim the credit against AMT and for certain small businesses to claim the credit against payroll (FICA) tax liability, rather than income tax. This was signed into law in H.R. 2029 the Consolidated Appropriations Act, 2016. (https://www.congress.gov/bill/114th-congress/house-bill/2029/text)

- The Agricultural Act of 2014 (P.L. 113-79)

On February 7, 2014, President Barack Obama signed into law a five-year reauthorisation of the Farm Bill, the Agricultural Act of 2014. The Farm Bill provided USD 881 million in mandatory funding for energy programmes, including for the first time incentives for renewable chemicals and product manufacturing. The legislation also included the BioPreferred programme to increase the purchase and use of bio-based products. (https://www.gpo.gov/fdsys/pkg/PLAW-113publ79/html/PLAW-113publ79.htm).

- H.R. 2883/S. 1656 Master Limited Partnerships (MLP) Parity Act

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. (https://www.congress.gov/bill/114th-congress/house-bill/2883).

*Source*: courtesy of Brent Erickson, US Biotechnology Innovation Organization (BIO)

74. 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.

## Technology clusters

75. Most OECD countries promote a cluster-based approach to innovation. The boundary between technology clusters and regional clusters in industrial biotechnology are blurred as both could carry out similar functions. Support for technology specialisation clusters exists in Australia, Belgium, Canada, Denmark, Ireland, Israel, Netherlands, New Zealand, Poland, Spain, Switzerland, the US and Singapore[13].

13 https://www.oecd.org/sti/outlook/e-outlook/stipolicyprofiles/interactionsforinnovation/clusterpolicyandsmartspecialisation.htm

76. The main rationale for public policies to promote technology clusters through infrastructure and knowledge-based investments, networking activities and training is an increase in knowledge spillovers among actors in clusters and thus the generation of a collective pool of knowledge that results in higher productivity, more innovation and an increase in the competitiveness of firms. This seems particularly relevant to industrial biotechnology as the collection of activities is so diverse, from fermenter engineering to genetic engineering.

77. One that is considered a true industrial biotechnology cluster is BE-Basic Foundation of the Netherlands[14]. The BE-Basic programme started in 2010 with an R&D budget of EUR 120 million, of which half is funded by the Ministry of Economic Affairs, Agriculture and Innovation as part of the Economic Structure Enhancement Fund (FES). It is a consortium of large industries, SMEs, knowledge institutes and academia. It is now an international PPP that develops industrial bio-based solutions, with an office in Campinas, Brazil and other strategic partnerships in Malaysia, the US and Vietnam.

***The Tianjin Institute of Industrial Biotechnology (TIB)***

78. The meteoric speed of development in China has caused the country to suffer a great deal from environmental deterioration and shortages of energy and other resources (Sun and Li, 2015). The response to the need for a national capability in industrial biotechnology in China was to form the Tianjin Institute of Industrial Biotechnology (TIB) within the Chinese Academy of Sciences (CAS)[15]. Co-founded with the Tianjin Municipal Government to lead industrial biotechnology development in China, it officially came into being in 2012 with a total investment of more than USD 100 million. Its mission is to establish a national innovation system for industrial biotechnology to promote eco-friendly development of the economy.

79. The institute is effectively a one-stop-shop for industrial biotechnology. Its research is boosted by technology platforms for robotic high-throughput screening, systems biology and industrial enzymes. Facilities move through research to pilot-scale production and scale-up. Domestic and international PPPs have been established with more than 60 companies to help overcome the barriers between scientific discoveries and commercial applications. As of December 2015, TIB had a total of 502 staff and graduate students. It has undertaken more than 400 research projects sponsored by Ministry of Science and Technology (MOST), National Natural Science Foundation of China, CAS, Tianjin Municipality, and other funding agencies or industries. The Tianjin Industrial Technology Innovation and Incubation Center of CAS was established at TIB, and it has created eight spin-out companies.

**SME and start-up support**

80. SMEs are the backbone of economies. In Europe they provide 85% of all new jobs. All high-technology SMEs face challenges in their specific sectors. In stark contrast to IT, biotechnology SMEs can face many years of high-risk research without revenues (Pisano, 2010), requiring expensive specialist facilities and complex market entry. Additionally, in bio-production they may well be in competition with some of the world's largest oil and petrochemistry firms that have proven markets, stable supply and value chains, proven technology and fully amortised production facilities. And yet governments place very high expectations on such firms.

81. Technology and regional clusters are a leading support mechanism for SMEs providing a range of services, such as: access to venture capital and other finance routes; business advice on the strategic use

14 http://www.be-basic.org/

15 http://english.tib.cas.cn/

of standards, labels, certificates, assistance with specific LCA and sustainability tools, access to demonstration and testing facilities.

82. COSME (Competitiveness of Enterprises and SMEs) [16] is a European programme implementing the Small Business Act. It runs from 2014 to 2020, with a budget of EUR 2.3 billion to support SMEs in: facilitating access to finance; supporting internationalisation and access to markets; creating an environment favourable to competitiveness, and; encouraging an entrepreneurial culture.

83. National government programmes can provide a wide range of support mechanisms, especially exemptions from tax and national insurance payments. The likelihood of success will be increased if there is diversity in mechanisms (Box 3).

**Box 3. SME and start-up support in Italy at national government level**

In late 2012, Italy embarked upon reforms aimed at developing a fertile start-up ecosystem. The Italian Startup Act represents a package of tools affecting all stages of business life cycle, aimed at creating the enabling conditions needed for quick go-to-market and scaling up. Innovative start-ups can profit from a vast array of benefits for five years, including:

- Exemption from fees normally due to the Chamber of Commerce;
- Opportunity to remunerate workers and consultants through stock options and work for equity schemes that are tax-deductible;
- Opportunity to raise capital in exchange for shares through equity crowdfunding portals;
- Robust tax incentives by up to 27% on seed and early-stage investment amounting up to EUR 1.8 million;
- Streamlined, free-of-charge access to public guarantees by 80% on bank loans amounting up to EUR 2.5 million.

Recently, Italy has also launched the *Italia Startup Visa* programme, which enables citizens from outside the EU intending to establish a high-tech company in Italy to obtain an entrepreneurship visa within 30 days, following an online and streamlined procedure.

The Italian Startup Act is an ongoing process that also draws on the analysis and evaluation of its empirical impact through a structured monitoring system involving the National Statistics Institute. In recent years, the Italian innovation ecosystem has grown rapidly: it has seen an average weekly increase of 40 start-ups and involves thousands of partners and employees.

*Source* : OECD (2015b).

### *Access to national expertise in bioprocess design*

84. Perhaps the greatest challenge facing the SMEs in bio-based production is scale up. In most countries risk capital is limited, and the cost of moving from laboratory pilot to demonstration scale is beyond the financial scope of most of these SMEs. As the bioeconomy grows and these applications of bio-based production expand, greater efficiency of public investments could be made through the public finance of regional bio-based production facilities at demonstrator and/or pilot scale. Models already exist e.g. the Centre for Process Innovation (CPI)[17] in the UK. CPI helps SMEs understand the commercial

[16] https://ec.europa.eu/growth/smes/cosme_en

[17] https://www.uk-cpi.com/work-with-us/smes/technology-focus

feasibility of products or processes in a way that reduces risk to the companies and their investors. Such facilities could maximise their benefits by offering a range of ancillary business services, such as training, quality management and certification.

***Access to laboratory facilities***

85. The Santa Fe Business Incubator (SFBI) is located close to the Los Alamos National Laboratory, New Mexico and several research universities. SFBI has supported a variety of entrepreneurs that have created more than 100 businesses. After years of planning, SFBI opened the BioScience Lab[18] in 2014, a laboratory that provides state-of-the-art equipment for early stage biotechnology companies in Northern New Mexico. It is the only shared biosciences laboratory in the region.

18 http://www.sfbi.net/services/BioScience_Lab/

## MARKET PULL (DEMAND-SIDE)

86. The OECD analysis on demand-side policies (OECD, 2011a) identified several general principles for governments to consider when applying demand-side policies. One that it is particular relevant when applied to industrial biotechnology and the bioeconomy more generally relates to timing and alignment.

87. This is the critical recommendation for demand-side measures for the bioeconomy as there are so many varied potential stakeholders involved e.g. Europe alone has some 16 million forest owners and 14 million farm owners (Hetemäki, 2014), and there are so many levels of government and different ministries/departments.

### Mandates and targets

88. Mandates and targets exemplify the different approaches to the introduction of biofuels in Europe and the US. Incorporation targets (i.e. targets of percentages of biofuels blended into gasoline and diesel) have been approved voluntarily by several EU member states as national initiatives, not an obligation from the EU. The US biofuels policy has specified absolute production quantities through a mandate rather than a less-binding incorporation target (Ziolkowska et al., 2010). Mandates and targets for biofuels production have become standard for introduction of biofuels in OECD and BRICS countries, (see OECD, 2014a).

89. Arguably the best-known mandate in bio-production was created in the US *Energy Independence and Security Act*[19] (EISA) (2007) through the Renewable Fuels Standard (RFS2) (Federal Register, 2010). It set high production volume mandates for biofuels. Together with blending mandates, a comprehensive policy support regime for biofuels came into being in the 21$^{st}$ century in the US.

90. 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.

91. However, if mandates do not distinguish among biofuels according to their feedstock or production methods, despite wide differences in environmental costs and benefits, governments could end up supporting a fuel that is more expensive than its corresponding petroleum product and with poorer environmental protection credentials (Global Subsidies Initiative, 2007). A key to preventing such a mistake in bio-based materials production support is, in the short term, harmonising life cycle analysis within the industry, and in the longer term developing robust and internationally coherent sustainability assessment.

### Public procurement

92. Public procurement affects a substantial share of world trade flows. It accounts for 13% of GDP on average in OECD member countries (OECD, 2012b). While there seem possibilities in public procurement for facilitating market entry for bioeconomy innovative products there are intrinsic obstacles on both sides of the market.

93. On the supply side, only a small proportion of the possible plethora of products from the bioeconomy addresses the business-to-consumer (B2C) market in which public procurers normally operate

19 www.govtrack.us/congress/bills/110/hr6

(e.g. fuel and consumer products). The larger share of bio-based products is chemicals and intermediates, which are only interesting to private industry in a business-to-business (B2B) market.

94. On the demand side public procurement is an incredibly fragmented landscape: in the EU at the central governmental level only, more than 2 100 procuring authorities are listed. The total number of public procurers in the EU (including regional and municipal level) is estimated at 250 000.

95. Moreover public procurers naturally tend to be very price-sensitive, which is a barrier for any innovative product. Various governmental schemes currently address this issue: the USDA BioPreferred Program[20] specifically aims to increase the purchase and use of bio-based products It has a catalogue containing around 14 000 bio-based products. In the EU the 2014 legislation for innovative public procurement concentrates on innovative solutions and even facilitates the development of innovative products but does not mention specific innovative products or product groups. Projects like the Forum for Bio-Based Innovation in Public Procurement (InnProBio[21]), however aim to enhance the market-uptake of bio-based products in public procurement.

**Promote standards and certification**

96. Stringent standards and certification give confidence to consumers and industry as they provide credibility to claims of performance and sustainability (Dammer and Carus, 2015), such as ‘bio-based’, ‘renewable raw material’, ‘biodegradable’, ‘recyclable’, or ‘reduced greenhouse gas impact’. They help verify claims such as biodegradability and bio-based content that will promote market uptake (OECD, 2011b). Claims ought to be verifiable by consumers, waste management authorities and legislators. Third party verification is a means to prevent unwarranted claims and green washing. The possibility of harmonising standards and labels at the international level could be studied and pursued if feasible.

97. The strategic importance of standards should not be underestimated. Standards provide a solid basis for introducing new products and technologies onto the market and a basis upon which further research and development can be built. They also help to remove uncertainties that companies face. Standards are developed in close cooperation between industry, research and policy makers, which is essential to create the right environment for new products and technologies to grow to full-scale deployment.

98. Standards and certification schemes are also joining-up measures between policy frameworks and practical implementation. Standards provide the necessary scientific basis for implementing legislation by demonstrating compliance with legal requirements. They can also be used to verify that policy goals and targets are being met. This is often visualised as the ‘golden triangle’ approach of regulation, standardisation and certification.

99. To help to develop the market for bioplastics, the Japan BioPlastics Association (JBPA)[22] started a certification programme for products containing biomass-based plastic content. The association has established standards as well as a methodology for the analysis and the evaluation of these plastics. The programme includes a logo easily recognisable by consumers. The JBPA certification, called BiomassPla, specifies that products with the logo must contain 25% bio-based plastic by weight.

20 https://www.biopreferred.gov/BioPreferred/faces/pages/FAQs.xhtml

21 http://www.biobasedeconomy.eu/innprobio/

22 http://www.jbpaweb.net/english/english.htm

100. Product labels should give clear and reliable information about the environmental performance of bio-based materials. This applies especially to bioplastics as these are the most likely to be contentious in society as a result of negative outcomes and perceptions from the use of petro-plastics. Today there are many different 'eco-labels'[23] in use globally, and the definitions and certification procedures differ widely. Significant efficiency gains may be had from promoting a harmonisation of eco-labels in the medium term.

### *Compostability certification and labelling*

101. Compostability is offered as an example of the importance of certification and labelling. A number of certification programmes have been developed. These are carried out by independent organisations that test the material or product and upon satisfactory results issue a certificate which guarantees that the material meets the requirements of a particular standard. If a compostability standard is performed by companies and is not third-party verified and certified, this opens the possibility of 'greenwashing'.

102. The purpose of certificates is to ensure that the users of these materials are aware of the relevant properties of the material (e.g. if it can be composted, landfilled, buried in soil or treated in aqueous media) (Krzan *et al.*, 2006). Due to this important role, certificates are often accompanied by a label that may be placed on certified polymeric materials and relevant plastic items. At present a number of certification programmes and corresponding labels are in place (Table 2).

**Table 2. Certification bodies for bioplastics**

| Certification organisation | Reference standard |
|---|---|
| Australian Bioplastics Association (Australia) | DIN EN 13432 |
| AIB Vincotte (Belgium) | DIN EN 13432 |
| Bureau de Normalization du Québec (Canada) | BNQ-9011-911 |
| Jätelaitosyhdistys (Finland) | DIN EN 13432 |
| Compostatori Italiano Consorzio (Italy) | DIN EN 13432 |
| Japan BioPlastics Association (Japan) | GreenPla Identification System |
| Keurmerkinstituut (Netherlands) | DIN EN 13432 |
| Avfall Norge (Norway) | DIN EN 13432 |
| Polish Packaging Research and Development Centre (Poland) | DIN EN 13432 |
| Association for Organics Recycling (UK) | DIN EN 13432 |
| Biodegradable Products Institute (USA) | ASTM D6400 |

### Fossil carbon taxes and emissions incentives

103. Carbon taxes could help guide bioeconomy to a sustainable pathway. OECD analysis shows that the most cost-effective way to mitigate climate change is to provide a strong and global price signal on carbon through the use of market mechanisms[24]. The purpose of carbon pricing policy frameworks today should be to send clear and credible price signals that foster the low-carbon transition over the medium to long term (OECD, 2015a). Explicit carbon prices can either be set through a carbon tax, expressed as a fixed price per tonne of emissions, or through cap-and-trade systems, where an emissions reduction target is set through the issuance of a fixed number of permits, and the price is set in the market through supply and demand.

104. Once politically unpopular, the number of countries, states, regions and cities developing carbon price mechanisms now accounts for about 12% of global emissions, a tripling of coverage in a decade (Rydge, 2015). Fears that a carbon price will damage industrial competitiveness seem to be receding.

23 http://www.ecolabelindex.com/

24 http://www.oecd.org/env/cc/44287948.pdf

105. Over 40 countries now have carbon pricing on energy. However, carbon prices are often set very low. Around 90% of emissions from energy use are priced at less than EUR 30 per tonne (the low-end estimate of the cost of carbon), and 60% of emissions are subject to no price whatsoever. The 'carbon pricing gap', a synthetic indicator showing the extent to which effective carbon rates fall short of pricing emissions at EUR 30 per tonne, sheds light on potential ways of strengthening carbon pricing (OECD, 2016a).

***Use carbon pricing revenues to support bioeconomy projects***

106. Governments can use carbon price revenues in a number of ways that should be guided by efficiency. Fiscal reform to reduce personal and business tax burdens can be one such use. British Columbia has used its revenues this way. One appropriate use would be to finance the energy and manufacturing transition that climate change is necessitating. Carbon taxation and the removal of fossil fuel subsidies are also necessities for meeting the sustainable development goals (SDGs) (El-Chichakli et al., 2016).

107. A proportion of these revenues could also be used for R&D projects targeting the bioeconomy (e.g. Box 4). It could be a cost-effective way to support long-term, higher risk research and more targeted short- to mid-term R&D, pre-competitive or near-market. By financing renewable energy projects, this is also a way to shelter governments from oil price volatility.

108. It is also suggested that governments put aside short-term crude oil prices and volatility for long-term planning. The private sector must necessarily respond to market forces, but governments must have a consistent vision of the future. For governments, low oil prices can be seen as an opportunity to better align policies with decarbonisation targets, especially accelerating the roll-out of carbon pricing mechanisms and dismantling fossil fuel subsidy programmes (IEA, 2016).

**Box 3. CCEMC and $CO_2$ Solutions, Canada**

In April 2007, Alberta became the first jurisdiction in North America to pass climate change legislation requiring large emitters to reduce GHG emissions. Two years later the Climate Change and Emissions Management Corporation (CCEMC) was created as a key part of Alberta's Climate Change Strategy and movement toward a stronger and more diverse lower-carbon economy.

The Government of Alberta administers the collection of all compliance funding each year and pools those funds in the Climate Change and Emissions Management Fund (CCEMF). The funds are sourced from industry and made available to the CCEMC through a grant from the Government of Alberta.

Alberta's Specified Gas Emitters Regulation identifies that facilities that emit more than 100 000 tonnes of $CO_2$ equivalent per year must reduce emissions intensity by 12% below a baseline. Organisations that are unable to meet their targets have three compliance options: make facility improvements to reduce emissions below the required threshold; purchase Alberta-based carbon offset or Performance credits; or pay CAD 15 into the CCEMF for every tonne they exceed the allocated limit.

The CCEMC manages its resources as a portfolio of projects with a wide spectrum of investments. The organisation funds projects at all levels of the innovation chain, with the bulk of its investment in projects at the demonstration and implementation phases.

For example, in 2012 and 2013, $CO_2$ Solutions (Quebec) secured CAD 5.2 million in grant funding from the Government of Canada's ecoENERGY Innovation Initiative and CCEMC towards a CAD 7.5 million project to optimise and pilot the technology for biological $CO_2$ capture from oil sands production (CCEMC, 2015).

The government of Alberta outlined a plan in November 2015 for cutting the province's GHG emissions. The proposals include an end to coal-fired power generation and a carbon price of CAD 30 per tonne to 2018 and rising in real terms after that. The plan has been backed both by environmental groups and by oil companies that are large producers in the oil sands.

## Fossil fuel subsidies reform

109. One more current barrier absent at the start of the 20$^{th}$ century was fossil fuel consumption subsidies. Fossil energy received a staggering USD 5.3 trillion, or 6.5% of global GDP, in post-tax subsidies[25] in 2015 (IMF, 2015). The IMF estimated that eliminating post-tax subsidies in 2015 could raise government revenue by USD 2.9 trillion (3.6% of global GDP), cut global $CO_2$ emissions by more than 20%, and cut premature air pollution deaths by more than half.

110. In the OECD countries over 550 fossil fuel consumption subsidies have been identified (OECD, 2012a). These had an aggregate value of the order of USD 55-90 billion a year over the period 2005-2011. 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.

111. Such measures are politically difficult and unpopular, no matter how necessary (The Economist, 2014). The environmental and social costs of fossil fuel subsidies (Whitley and van der Burg, 2015) are unlikely to be obvious to the public and may even be masked for finance ministers (Edenhofer, 2015). And yet, it is estimated that on average only 7% of the benefits from fossil fuel subsidies reach the poorest 20% of the population. Governments could use the money saved to fund decarbonisation projects and technologies (Martin, 2016), as exemplified by the bioeconomy.

[25] The large difference between pre- and post-tax subsidies largely reflects the local and global environmental damage from energy consumption.

## CROSS-CUTTING POLICIES (MIX OF SUPPLY- AND DEMAND-SIDE)

### Metrics, definitions and terminology

112. Definitions are necessary in any economic activity to gather data that are comparable across regions, countries and globally. This will be evident from the discussions on biomass sustainability. Robust data are needed to build metrics for the performance of a bioeconomy. ‘Bioeconomy’ itself means different things in different countries. A definition of ‘bio-based product’ is needed as a standard for public procurement and business development. There are several types of biorefinery in operation and under development: each needs a definition to differentiate one from the other.

113. The debate over ‘waste or resource’ (e.g. House of Lords, 2014; UK Department for Business Innovation & Skills (2015) is an important one for the bioeconomy. A mixture of terms and a lack of standardised definitions make it very difficult to truly assess the volumes of different waste materials that can be used in biorefining. For example, gathering data on ‘agricultural residues’ suffers from this. This compares poorly with the easily identifiable volumes that would be available from crop feedstocks, such as volumes of sugar cane or sugar beet: these figures are collected internationally and are readily comparable.

114. A key objective of biorefining, especially for second generation biofuels and bio-based materials, is the valorisation of waste (Fava et al., 2015). ‘Bio-waste’ is acquiring greater importance in biorefining, and tonnages should be known when formulating biorefinery roadmaps. However, any definition that excludes agricultural or forestry residues drastically changes available estimates of tonnages. The definition of ‘waste disposal’ could be changed to allow collection, transportation, sorting in view of its conversion in biorefineries. Effectively, if a material is to be converted in a biorefinery then it should no longer be regarded as a waste but as a resource.

115. Ultimately, integration of actors across sectors and hence the creation of new value chains is limited by disparity and lack of control of terminology and standards. In short what is called for is *commonly agreed vocabulary throughout value chains, from feedstock suppliers to biorefining to downstream actors in the application sectors*[26].

### Design skills and education initiatives with industry to train the workforce of the future

116. There are essential differences between the scientific method (test a hypothesis through experimentation) and engineering design (design a solution to a problem and test the outcome)[27] that have to be addressed.

117. For many, synthetic biology is a field of engineering, not of biology (Andrianantoandro et al., 2006). Synthetic biologists must be grounded in one or several core disciplines: genetics, systems biology, microbiology, or chemistry. But they must also draw on engineering—to be able to break down biological complexity and standardise it into parts, or design new biological systems and components, drawing on the quantitative approach of engineering. This requires skills in mathematics, computing, and modelling (Delebecque and Philp, 2015). Multi-disciplinarity is a recurring them in industrial biotechnology education.

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26 http://cordis.europa.eu/programme/rcn/700101_en.html

27 http://research.uc.edu/sciencefair/resources-forms/topic-suggestions/scientific-method-v-engineering-design-procedures.aspx

118. It is difficult for the young bio-based production industry to find automation engineers specialising in high throughput strain production. It has for a long time been difficult to find fermentation staff. Perhaps hardest to find of all are employees well versed in experimental design and statistics, possibly due to an over-reliance on the one factor at a time (OFAT) teaching in the scientific method (Sadowski et al., 2016). This is especially important now that dealing with large data sets is becoming more common. All are necessary in bio-based production. The essential problem just now is that they are not required in large numbers, and this business sector is very much a small niche sector, so it is difficult for governments to prioritise education in these directions (OECD, 2014b). However, a demand for 10 000 bio-based experts is expected in the next ten years in the Netherlands alone (Langeveld et al., 2016).

119. Scotland faces a series of challenges in maximising its development of industrial biotechnology, which includes skills shortages. In direct response to industry need, the Industrial Biotechnology Innovation Centre (IBioIC)[28] has created bespoke educational programmes to specifically meet this need across all educational levels from Modern Apprenticeships, Higher National Diploma (HND in Industrial Biotechnology), the UK's first collaborative MSc in Industrial Biotechnology and PhD studentships with Universities across Scotland and industrial partners across the UK[29]. IBioIC has been tasked with generating GBP 1-1.5 billion of GVA to the Scottish Economy by 2025 from the industrialisation of biology, and it requires a pipeline of talented people to deliver this. Here is the recognition of the need for a workforce, not just a research capability.

***Include managerial and transferrable skills***

120. The typical MBA programme is not suited to the biotechnology industry generally. The industry is typified by rapid change and change management is an important issue. There have already been examples of short programmes for managers in industrial biotechnology that allow them to keep up with developments without leaving their post for long periods e.g. a so-called 3-day MBA[30]. In 2015, Synbicite in London ran a 4-day MBA[31] to cover the main strategies required to establish, build and manage a biotechnology company based around synthetic biology.

121. For decades there have been discussions about making research degrees more flexible (National Academy of Sciences, 1995) with the inclusion of transferrable skills training. Today's researchers need skills relating to communication, problem-solving, team work, networking and management know-how. The literature identifies several benefits of formal transferrable skills training that can add value (OECD, 2012c).

***An international Massive Open Online Course (MOOC) in industrial biotechnology***

122. The traditional on-campus experience is bound to be revolutionised by the explosion of Massive Open Online Courses (MOOCs), which will enhance, if not partially replace classroom and laboratory work. A specialist MOOC for industrial biotechnology is offered jointly by the Technical University of Delft (Netherlands) and the University of Campinas (Brazil). It provides the insights and tools for the design of sustainable biotechnology processes. The basics of industrial biotechnology are used by students for the design of fermentation processes for the production of fuels, chemicals and foodstuffs. Throughout

28 https://www.ibioic.com/

29 http://www.3bi-intercluster.org/home/

30 http://flandersbio.be/events/3-day-mba-industrial-biotechnology-/

31 http://www.synbicite.com/media/attachments/SynbiCITE_4_day_MBA.pdf

this course, students are challenged to design a biotechnological process and evaluate its performance and sustainability[32].

***Public-private partnerships for specialist training facilities***

123. For early-career scientists gaining access to bio-based production experience is difficult. Universities do not normally have such facilities. An interesting training model is the National Institutes model in Ireland. One of these is a dedicated facility for training in bioprocessing (the National Institute for Bioprocessing Research and Training, NIBRT[33]). For a relatively small country, Ireland has a large pharmaceuticals sector. The institute builds tailored training solutions for clients, ranging from operator through to senior management training, and training can be delivered in a realistic GMP-simulated manufacturing environment. This type of environment is not one found typically in universities, and is more appropriate for the training of industry professionals. Such a facility could also be used to give students exposure to industry working conditions.

124. Another possibility is to offer placements in organisations such as IROs like Fraunhofer in Germany and VTT in Finland, or in research institutes like CSIRO in Australia, RIKEN in Japan and KRIBB and KAIST in Korea (Box 5). This allows opportunities to learn hands-on skills without academic baggage.

32 https://online-learning.tudelft.nl/courses/industrial-biotechnology/

33 http://www.nibrt.ie/

**Box 4. Research organisations and industrial biotechnology**

Several well-known research organisations offer services diversified from research in industrial biotechnology. These could prove pivotal in capacity building for national bioeconomies. A selection of these is given.

**Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia**. CSIRO works with a wide range of industries: agriculture and food, health and biosecurity, digital, energy, land and water, manufacturing, mineral resources, and oceans and atmosphere. Research is done specifically in industrial and environmental biotechnology in the areas of: bioprocesses for sustainable resource management; biological catalysts for sustainable industries, and; understanding metabolic processes.

The organisation is working on using eucalyptus waste streams at timber or paper mills for manufacturing bio-PET bottles and packaging[34]. These bio-based aromatic chemicals can be further converted to high-value derivatives to replace petroleum-derived additives in packaging materials. Expertise developed in biocatalysis and enzyme engineering is being extended to the development of synthetic biology capability. CSIRO has developed and patented an efficient enzyme nano-factory system, comprising several different nano-machine reactors that can convert glycerol into high-value molecules such as pharmaceuticals[35].

**RIKEN, Japan**. RIKEN is the largest research organisation for basic and applied science in the country. It combines basic research with a focus on innovation. The RIKEN Biomass Engineering Program combines several research areas, such as bioplastics, synthetic genomics, enzyme research, cellulose research, cell factory research, and also has a business development office that promotes collaboration based on the needs of industry. For example, the cell factory research team has biosynthesised 4-vinyl phenol, the monomer of a plastic with similar properties to polystyrene (Noda et al., 2015). The RIKEN Junior Research Associate (JRA) programme in Japan provides part-time positions at RIKEN for young researchers enrolled in Japanese university PhD programmes. This gives PhD students the opportunity to carry out research alongside RIKEN scientists and it also strengthens the relationships between RIKEN and universities in Japan.

**The Korea Research Institute of Bioscience & Biotechnology (KRIBB), Korea**. KRIBB has dedicated centres that respond to the needs of bio-based production: the Industrial Bio-materials Research Centre; the Biochemicals and Synthetic Biology Research Centre; the Cell Factory Research Centre; the Biotechnology Process Engineering Centre. It also has a SME Support Center that supports capacity building and growth of bio-based SMEs.

**Korea Advanced Institute of Science and Technology (KAIST), Korea**. KAIST is a world-class centre for metabolic engineering with a strong focus on bio-production of industrial platform chemicals and biopolymers (Lee et al., 2011). There are at least three centres at KAIST that contribute to work in industrial biotechnology: Centre for Systems and Synthetic Biotechnology; the BioProcess Engineering Research Centre and the BioInformatics Research Centre.

## Competitive regional clusters

125. As a result of globalisation, many regions that were historically production centres in a given sector are losing out to lower-cost locations and reorienting to higher value-added niches. One response is national programmes to promote cluster-based approaches that link firm, people and knowledge at a regional level. Evolutions in regional policy, science and technology policy and industrial/enterprise policy are converging on the objective of supporting clusters at the regional level.

34 http://www.csiro.au/en/Research/MF/Areas/Chemicals-and-fibres/Chemistry-and-biotechnology/Biotechnologies

35 http://www.csiro.au/en/Research/LWF/Areas/Environmental-contaminants/Environmental-industrial-biotechnology/Biocatalysts/Molecular-machines

126. However, regional clusters are not without risks (OECD, 2007). These can often relate to a lack of engagement by the private sector. The long-term effectiveness of such policies depends on the private sector continuing to act after a programme ends. There is a strong interaction here with policy coherence and durability, as the bio-based private sector continues to campaign for stable, long-term policy.

127. If the regional cluster policy did not exist, it could have been invented for industrial biotechnology, for several reasons:

- Here is a R&D-intensive technology that requires a feedstock that is mainly found in rural environments (food and non-food crops, wood, forest and agricultural residues). In other words, the *preferred* location for industrial biotechnology is regional, not urban;

- R&D centres and public research organisations, however, tend not to be rural, and therefore need some mechanism to connect them to the other actors across the industrial biotechnology value chain;

- The stakeholder groups are so diverse. They include farmers, foresters and their trade associations and cooperatives, buyers, agricultural and forestry machine rings, hauliers and other logistics professionals, chemicals and fuels companies, biorefiners, venture capitalists, food companies, R&D organisations, technology SMEs, waste management companies, regulators, recycling and waste management organisations.

128. European countries have used the regional cluster mechanism frequently to build capacity in industrial biotechnology e.g. Belgium, France, Germany, Italy, Netherlands, UK – all countries with large and strategic chemicals sectors. In 2006 the German Federal Ministry of Research and Education initiated a cluster competition to strengthen industrial biotechnology in Germany. Five industrial biotechnology clusters were selected and received funding in total of EUR 60 million.

129. A successful cluster in France with tangible results and benefits is Industries & Agro-Ressources (IAR). With over 200 members, the ‘Industries & Agro-Ressources’ (IAR) cluster in the Champagne-Ardenne and Picardy regions of France unites stakeholders from research, education, industry and agriculture in France around a shared goal: to optimise the added value from the exploitation of biomass. It has regional roots where biorefining has been particularly successful, it also has a global mission by integrating external know-how through international strategic alliances. A classic task of a regional cluster, IAR assembles stakeholders from the whole value chain around a shared innovation problem.

130. The IAR cluster is strong and successful. A particular strength is its range of activities downstream of R&D that is necessary for technology capacity building. The cluster has been involved in R&I projects to a value of around EUR 1.5 billion. It has responded to the special challenges of fund raising for the shift from demonstration to commercialisation within SMEs by creating IAR-Invest[36]. It offers an inclusive service for innovative companies to: increase their visibility with private investors, especially the venture capital community; and to arrange interaction with multiple stakeholders to improve the prospects for securing investments e.g. funds, banks, regional councils, incubators and financial institutions.

### *Encourage clusters to become international*

131. International agreements can bring several benefits: sharing of technology, mobility of people, tackling of international issues such as biomass sustainability, trade and tapping into international funding

36 http://www.iar-pole.com/cluster/services/iar-invest?lang=en

programmes. This also helps demonstrate to governments that their national investments are valid in an international context.

132. A notable example in the current context is BIG-C (BioInnovation Growth mega-cluster). It is a cross-border Smart Specialisation initiative aiming at transforming Europe's industrial mega cluster in Flanders, the Netherlands and the German state of North-Rhine Westphalia (NRW) into the global leader of bio-based innovation growth. The German Federal Ministry for Education and Research, as part of its "Internationalisation of Leading-Edge Clusters, Forward-Looking Projects, and Comparable Networks" strategy, will support the project with up to EUR 4 million over the coming years.

133. Bio Base NWE is a project funded by the Interreg North-West Europe 2014-2020 Programme[37]. Eight partners from five European countries (Belgium, Germany, Ireland, The Netherlands and the UK) are involved in this three-year project. The overall aim of Bio Base NWE is to support the development of the bio-based economy in NWE by facilitating innovation and business development by SMEs and improving professional training and education for the bio-based economy.

## Governance and regulation

### *Governance has to be multi-level*

134. OECD analysis suggests that innovation heavily depends on issues of their governance and implementation (OECD, 2015b). Governance matters in innovation policy due to various levels of authority and policy competencies involved. Budgetary resources are distributed across various levels of government when horizontal policy is created. Regionalisation and decentralisation have made regional and local governments more powerful and has increased their capacity to operate their own development policies. This is particularly important in industrial biotechnology and bioeconomy. But bioeconomy also spans national and global connections, creating the need for multi-level governance, which is not easily achieved. The OECD *Recommendation of the Council on Effective Public Investment across Levels of Government* (OECD, 2014d) offers a framework for addressing public investment in a multi-level governance context.

135. Coordination is the key to horizontal governance. Poor coordination can lead to duplication, inefficient spending, a lower quality of service and contradictory objectives and targets. Better governance takes on an imperative when systems innovation is involved, as is the case with the bioeconomy. The full set of policies that are involved should be aligned. This takes on a special significance for industrial biotechnology and the bioeconomy as so many policy goals are involved, such as: reindustrialisation (e.g. European Commission, 2013); rural development, essential for achieving the United Nations Sustainable Development Goals; circular economy (e.g. European Commission, 2015a); smart specialisation (OECD, 2013a).

### *Poor regulatory policy can do more harm than good*

136. Regulation crops up in various places in this paper. For example, public policy to regulate and enforce biomass sustainability would aim to prevent illegal logging and deforestation. Regulation refers to the implementation of rules by public authorities and governmental bodies to influence the behaviours of private actors in the economy. The primary purpose of regulation in innovation policy should be to enable

37 http://www.nweurope.eu/5b/

and, where possible, stimulate innovation, although the opposite is undeniably possible[38]. Complex and time-consuming regulation is far more damaging to small bio-based companies than it is for large companies. Governments could act to reduce this impact.

137. 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.

138. In the bioeconomy a frequently mentioned example of successful regulation to stimulate innovation is the single-use plastic bag ban in Italy (e.g. OECD, 2013c). In January 2011, Italy promoted a first-of-kind regulation aimed at replacing traditional plastic carrier bags with biodegradable and compostable bags (compliant to the harmonised CEN Standard 13432) and reusable long-life bags. This is considered to have triggered various effects in Italy including new investments in bioplastics production, with positive cascade effects along the value chain. It created improvements in waste management. And Italian citizens adopted behaviour that has a positive impact on environmental sustainability.

**Communication and raising awareness**

139. Information campaigns for consumers can strengthen the demand for bio-based materials when they convey to the consumers that bio-based products possess many ecological advantages. In this case, official labels for bio-based products would strengthen the public awareness of bio-based plastics and their products and would strengthen the trust placed in such products, therefore supporting the market introduction and establishment.

140. Communication is vital for public acceptance, especially as bio-based production has already been associated with genetic modification. For the public, cost is likely to be a driving factor, but environmental benefits can be important in some countries. In this case communication of the benefits takes on an even more important role, especially if the bio-based product is more expensive (see Box 7).

141. The Global Bioeconomy Summit in Berlin, November 2015 attracted over 700 participants from about 80 countries around the world. Its International Advisory Committee agreed on seven measures to be taken and discussed during the plenary (Global Bioeconomy Summit Communiqué, 2015), four of which were directly about communication:

[38] The EU has a new innovation principle, which aims to ensure that each new regulation is assessed on its impact on innovation: https://ec.europa.eu/epsc/publications/strategic-notes/towards-innovation-principle-endorsed-better-regulation_en

1. To establish an international forum for bioeconomy as an informal network to foster strategic dialogue with policy-makers, private sector, civil society and scientists, including foresight and think tank oriented activities;

2. To initiate a dialogue among stakeholders regarding the knowledge, skills and competencies, which will be crucial for implementing the bioeconomy, and to promote mutual capacity building efforts;

3. To build up dialogue with civil society and the interested publics to render bioeconomy a venture based on a widely shared vision of a sustainable future; innovative ways of communication with the public must be identified and developed, based on principles of transparency, openness and evidence;

4. To include bioeconomy topics into ongoing discussions on how to achieve the Sustainable Development Goals at international and national levels.

## PUTTING IT ALL TOGETHER: SYSTEMS INNOVATION FOR A JOINED-UP BIOECONOMY

"*Declining access to conventional oil, in combination with our joint responsibility to stop global warming, will be a test of the world community's readiness to switch to energy systems that are more sustainable in the long term. Basically, it is a question of the will to show solidarity with present and future generations. Sweden accepts this challenge!*".

Commission on Oil Independence (2006)

142. Systems innovation is a horizontal policy approach to use combined technologies and social innovations to tackle problems that are systemic in nature[39]. It involves many actors outside of government (as well as different levels of governments) and takes a longer term view. Systems innovation occurs when the societal system functions differently and thus there is a requirement for fundamental structural change (Frantzeskaki and De Haan, 2009). Bioeconomy fits the need for systems innovation, just like the transitions from wood to coal and from coal to oil.

143. To understand the transition to a bioeconomy, it may be useful to examine a well-defined example that can be used to understand some salient policy features and how things can go wrong. There is already a good example; the transition in Sweden from fossil to renewable fuels. In 2005 the government of Sweden appointed a commission to draw up a comprehensive programme to reduce the country's dependence on petroleum, natural gas and other fossil raw material by 2020. In June 2006 the commission issued its report, entitled *Making Sweden an Oil-Free Society* (Commission on Oil Independence, 2006). Now the Swedish government's ambition is to have a fossil-independent vehicle fleet by the year 2030 (Hellsmark et al., 2016). This is strongly dependent on ethanol as a renewable fuel.

144. It called for systems innovation but the goals may have been derailed (Box 6). There are various lessons to be learned from this Swedish example. First of all, the obvious one is that policy and policy coordination is required, even for a country with a relatively small population. More importantly, all the policy effort can be wasted without due attention to public opinion and acceptance.

39 https://www.innovationpolicyplatform.org/system-innovation-oecd-project

**Box 5. Sweden, ethanol, systems innovation and public acceptance**

To transition from gasoline to ethanol requires flex-fuel vehicles that can use E85 fuel (85% ethanol/15% gasoline). At first these were imported to Sweden. Ford introduced the first model in Sweden in 2002. From 2005 Saab and Volvo chose to enter the market. In the years that followed, the number of models continued to increase and by 2010 there were 74 different models to choose from. Each year sale shares increased, reaching in 2008 almost 25% of the market. But since then the sales have dropped to 5% of new sold cars in 2011.

In the new system, the cars are part of the demand-side, but a FFV can also burn straight gasoline. Therefore it is necessary first to provide infrastructure to be able to purchase E85, and also to incentivise its purchase if it is more expensive than regular gasoline. Ethanol, or rather alternative fuels, have thus received a lot of support from the Swedish authorities, from mandating an alternative fuel at fuel stations to subsidising sales of vehicles. The range of measures includes:

- A SEK 10 000 (over EUR 1 000) rebate for FFV buyers;
- 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 fuel stations selling more than 3 million litres of fuel annually have been required to sell at least one type of biofuel (Swedish Parliament 2009).

Fuels in Sweden are subjected to both a carbon and an energy tax. Biofuels have however been exempt from these taxes to make them more price competitive and thus increase the uptake (Sandebring, 2004).

For private owners in April 2007 the rebate of SEK 10 000 was introduced for so called ‘green’ vehicles. FFVs with gasoline consumption below 9.2 litres per 100 km were included. The rebate was handed out until the end of June 2009. It was replaced by a five year exemption from the annual circulation tax. This tax is based on the $CO_2$ emissions of the vehicle, thus varies from model to model. Part of the reduction in sales among private owners can be explained by the change in rebate structure. However, the total sales of ‘green’ vehicles have continued to increase, thus it seems that sales of conventional vehicles with emissions under 120 grams $CO_2$ per km have not been as affected by the change in rebate structure, especially new diesels (Sprei, 2013).

Many advantages were seen with the fuel: it had the possibility to easily reduce $CO_2$ emissions; the potential of national fuel production both through wheat ethanol and lignocellulosic ethanol; providing the owner with an economic benefit when gasoline prices increased. By the end of 2007, however, more negative voices started to be heard questioning the environmental advantages of the fuel and when food prices started to increase globally the connection to increased biofuel use was swiftly made, rightly or wrongly. Emissions connected to indirect land use change and other production-related emissions were highlighted and weakened the image of ethanol as a green fuel.

There was a lot of media coverage on these perceived disadvantages and public opinion started to turn against ethanol. At the same time diesel vehicles that met the criteria of being green started entering the market and offered a possibility to substitute FFVs. The price of E85 has not been low enough to compete, despite high subsidies. There were few compelling arguments left for choosing a FFV compared to a low-emissions diesel vehicle. Subsidies may manage to create a market at first but this cannot be sustained for a long time and thus there needs to be something more appealing in the long run.

## *ESTO VIGILANS*: SEEK OUT POLICY CONTRADICTIONS

145. It will be immediately clear that policy developments in all three areas of Figure 2 require that policy is coherent across the boundaries, that duplication is minimised, and that policies remain sufficiently flexible to prevent bottlenecks and expensive lock-ins. One of the tasks of systems innovation, then, is to patrol the different policies to identify synergies; perhaps more important is to identify the policy clashes and incompatibilities. This needs a policy rethink: policies that are vertical in nature and target a particular field, sector, technology or location no longer suffice on their own. They need to be complemented by a horizontal – whole of government – policy approach to innovation (OECD, 2010b). This is highly relevant to the bioeconomy. Governments need to be aware of the possibilities of policy conflicts with other major areas of policy. For multiple countries and regions, it would not be possible to identify all of these. Instead, Table 3 gives some examples of where bioeconomy may interfere with other policies.

**Table 3. The bio-based production policy trinity and how it may interfere with other major policy areas.**

| Policy goal | Potential policy conflicts | Example | Comment |
|---|---|---|---|
| Biofuels production | Energy | Fossil fuel consumption subsidies | Biofuels have to compete on price, but the fossil fuel market is highly distorted. |
| | Agriculture | Food versus fuel | Really about competition for land. |
| | | Set-aside (and its suspension) | Increased cropping for biofuels is sometimes associated with set-aside suspension. |
| | International trade | WTO regulations | Discrimination rules, such as ‘like’ products, and between different types of biofuels. |
| | Transport | Mandated production | Ethanol blend wall shows a need for a balance of supply and demand policies. |
| Increased biomass use | Energy | Bioenergy and wood pellets | Feed-in tariffs for bioenergy applications. |
| | Environment | Waste regulations | Collecting waste may contravene waste licensing regulations. |
| | | Climate change | Non-renewable energy consumption for collection. |
| | Agriculture | Food versus fuel | The debate is on-going. |
| | | Set-aside | More land needed, perhaps conflicts with set-aside in applicable countries ? |
| | | ILUC[40] | Some say impossible to measure, but ILUC may be written into policy. |
| | | Sugar regime | How may cellulosic sugar conflict with the sugar regime ? |
| Low volume chemicals | Climate change | Low production volume | Do low volumes create enough climate change benefit to justify policy support ? |
| | International trade | State Aid rules | How the production may effect or affect trade between states. |
| High volume chemicals | Biofuels | Biomass pricing | Level playing field for bio-based material use. |
| | Bioenergy | Biomass pricing | Level playing field for bio-based material use. |
| Bioplastics | Environment | Landfill use | Will biodegradable plastics degrade in an anaerobic landfill environment ? |
| | | Climate change | Biodegradation increases GHG emissions. |
| | | Composting | Compliance with standards. |
| | | Incineration | Efficient end-of-life option may depend on energy recovery. |
| | | Climate change | GHG emissions lowest through recycling of durable bioplastics ? |
| Aromatics | Chemicals regulation | Stockholm Convention | Phasing out of toxic chemicals. |
| Rural biorefineries | Environment | Brownfield policies | Building biorefineries may need greenfield sites. |
| | | Infrastructure | Cooling water. |
| | Transport | Infrastructure | New rail/road links, pipelines. |
| | Energy | Infrastructure | New sub-stations, distribution. |
| | Employment | Relocation | From city to rural life. |
| | Trade | Competitiveness | Economies of scale with petro-refineries (large, integrated, often coastal). |
| Marine biorefineries | Environment | Waste | Available waste $CO_2$. |
| | | Waste | $CO_2$ capture. |

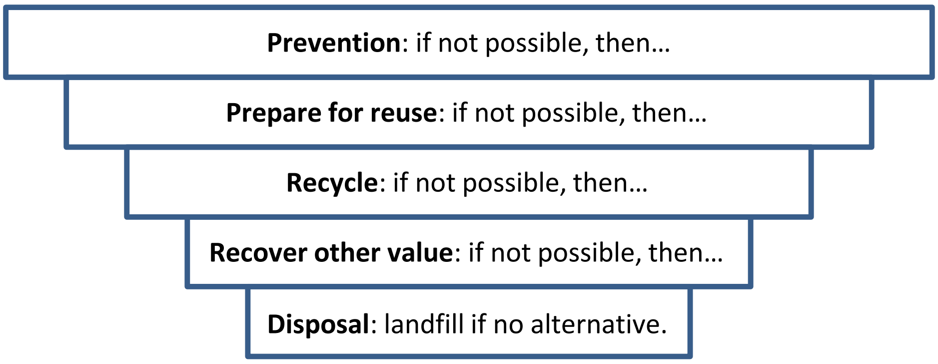
*Source:* OECD (2014b)

40 Indirect land use change

**Waste management and the bioeconomy**

146. The waste hierarchy presents a potential clash with biorefining policy goals (Figure 7). The objective is to minimise organic waste going to landfill (EEA, 2009). In the waste hierarchy, bio-based production could be in either “Recover other value” or “Recycle” (if the feedstock is a waste), with categories above that provide no added value. This could exclude feedstocks from higher value-added uses.

**Figure 7. The waste management hierarchy**




147. On the other hand, if a feedstock for biorefining is domestic waste that would otherwise be recycled, then biorefining and bioeconomy policy clashes with established infrastructure and markets for recycling, which are at the heart of the circular economy concept.

148. Denmark illustrates the point. Denmark is known for visionary environmental and energy policies combined with coherent public planning. As a result it has one of the most efficient waste management systems in Europe. The flexible of its waste management allows for the operation of the famous and decades-old waste exchange at Kalundborg, in which a waste product from one business becomes a feedstock in another (Erkman, 1997). However, domestic waste management in Denmark is based on high levels of waste incineration with energy recovery. Large sums have been invested in the infrastructure and logistics of incineration. This would effectively exclude domestic waste as a feedstock for biorefining without flexible policy.

## CONCLUDING REMARKS

149. This report may paint a rosy picture of lots of international effort and cooperation, plenty of infrastructure investment and therefore a booming bioeconomy sector. This is illusory. What it actually demonstrates is the beginning of the transition to a new model of production, one based on decentralisation and sustainability (*Il Bioeconomista*, 2016). Several countries are strong in bioeconomy research and relatively poor in deployment. In terms of biorefining capacity, perhaps Finland is in the lead. However, the cellulosic biorefineries, upon which great hopes are pinned, are proving worryingly susceptible to technical failure. To date, cellulosic ethanol volumes are still but a trickle, and still dependent on government largesse (Peplow, 2014). Clearly research progress is way ahead of full-scale deployment, not a surprise in such a young industry. This paper points to the major policy needs to redress the balance between R&D and commercial success. It is a long and tortuous journey.

150. Schieb et al. (2015) forecast that, in order to make the industrial bioeconomy a success the number of biorefineries, both in the US and Europe, would have to be increased to 300-400. That represents a very large investment, most of which will need to come from the private sector. In many engagements with the bio-based private sector the most consistent message that comes across is that policies have to be stable and long-term so that the private sector has the confidence to invest in risky projects.

151. One suggestion has been to have a 15-25 year competitive advantage over the fossil industry (*Il Bioeconomista*, 2015). Expensive as that may seem, fossil subsidies, after a century of operation of the fossil industries, remain very high, and climate change is real. The messages are getting through to the fossil industry. Progress is being made when the Rockefeller Family Fund trustees say: "*While the global community works to eliminate the use of fossil fuels, it makes little sense - financially or ethically - to continue holding investments in these companies*" (Cunningham, 2016). Even Saudi Arabia plans to diversify its economy and end its reliance on oil in the near future[41].

152. The biggest stimulus may now come from China and the US having ratified the Paris Agreement in 2016. There is a concentration of effort in policy circles on carbon pricing, and this has the potential to raise very large revenues for governments. It remains then for policy makers to spend their new bounty on technologies to decarbonise energy and production. The bioeconomy is part of both the future energy and production landscapes in many scenarios. It is hoped that this paper can show the way to making a framework for policy makers to spend that bounty efficiently.

41 http://vision2030.gov.sa/en/media-center

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