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Foreword

There are around 1 000 biorefineries worldwide. Their construction can proceed almost according to an engineering formula. A much harder task for the development of a successful bioeconomy is creating the ecosystems of companies and the value chains that support the activities of biorefineries or other bio-based production plants. Bio-based value chains and products are new and untried, the markets under-developed and even public awareness is lacking. Furthermore, many of the products are in direct competition with a fossil-based competitor. The fossil economy has been developed over many decades and the production processes have been perfected, the production plants fully amortised. For companies trying to enter bio-based production there are many risks, and a primary focus for public policy must be de-risking through various instruments to allow the bioeconomy to gain momentum.

Specific and novel insights into emerging value chains required qualitative case studies based on face-to-face interviews involving as many country delegations as possible. The resulting country case studies created for this project are the evidence base for an analysis of how countries are enabling the industrial and innovation ecosystems needed to achieve goals set by national strategies and policies on bioeconomy. This report acts as the final output for this project. The extended case studies can be found in an Annex to this report available at www.oecd.org/sti/emerging-tech/innovation-ecosystems-in-the-bioeconomy-annex.pdf

The project was supported and informed by a series of six workshops, and some of the materials in this Policy Report are inputs from workshops that did not necessarily arise in the case studies. These include:

- “New innovation ecosystems and circular solutions to boost the bioeconomy”, World Circular Economy Forum, Helsinki, Finland, June 07, 2017
- “Successful industrial examples of Circular Bioeconomy in Italy”, Ecomondo 2017, Rimini, Italy, November 09, 2017
- “The circular bioeconomy industrial ecosystem project”, Paris, France, May 03, 2018
- “Building a biomass innovation ecosystem in a circular bioeconomy in Poland”, Kraków, Poland, June 07-08, 2018
- “Circular Bioeconomy: national case studies of innovation ecosystems”, Ecomondo 2018, Rimini, Italy, November 07, 2018
- “Water cycle management and municipal bio-waste exploitation in the context of circular economy: from concept to standard practice”, Ecomondo 2018, Rimini, Italy, November 08, 2018

The paper summarises the value chains and the main findings from the country case studies supplied to the Secretariat, with specific materials taken from the various workshops that supported the project. The paper was written by Jim Philp and David Winickoff. This report has been reviewed by the Working Party on Bio-, Nano- and Converging Technologies (BNCT) and declassified by the Committee for Scientific and Technological Policy (CSTP).
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreword</td>
<td>3</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>4</td>
</tr>
<tr>
<td>Executive summary</td>
<td>6</td>
</tr>
<tr>
<td>1. Introduction</td>
<td>8</td>
</tr>
<tr>
<td>1.1. Transitions</td>
<td>8</td>
</tr>
<tr>
<td>1.2. The promise of an innovation ecosystems approach</td>
<td>11</td>
</tr>
<tr>
<td>1.3. Primary study questions</td>
<td>12</td>
</tr>
<tr>
<td>1.4. Key findings of the study</td>
<td>12</td>
</tr>
<tr>
<td>2. Methodology</td>
<td>16</td>
</tr>
<tr>
<td>2.1. Qualitative case studies across countries</td>
<td>16</td>
</tr>
<tr>
<td>2.2. Case study selection criteria</td>
<td>17</td>
</tr>
<tr>
<td>2.3. What follows: summaries of the case studies</td>
<td>18</td>
</tr>
<tr>
<td>3. Belgium (Flanders): a summary of regional ecosystems</td>
<td>19</td>
</tr>
<tr>
<td>3.1. The ecosystem(s)</td>
<td>19</td>
</tr>
<tr>
<td>3.2. Main policy conclusions</td>
<td>21</td>
</tr>
<tr>
<td>4. Canada: the Sarnia-Lambton cluster</td>
<td>22</td>
</tr>
<tr>
<td>4.1. The ecosystem(s)</td>
<td>22</td>
</tr>
<tr>
<td>4.2. Main policy conclusions</td>
<td>23</td>
</tr>
<tr>
<td>5. China: abundant agricultural residues as feedstock</td>
<td>25</td>
</tr>
<tr>
<td>5.1. The ecosystem(s)</td>
<td>25</td>
</tr>
<tr>
<td>5.2. Main policy conclusions</td>
<td>26</td>
</tr>
<tr>
<td>6. Finland: business ecosystems related to biomass-based textiles and plastic substitutes</td>
<td>28</td>
</tr>
<tr>
<td>6.1. The ecosystem(s)</td>
<td>28</td>
</tr>
<tr>
<td>6.2. Main policy conclusions</td>
<td>29</td>
</tr>
<tr>
<td>7. France: a private sector case study – Bazancourt-Pomacle</td>
<td>31</td>
</tr>
<tr>
<td>7.1. The ecosystem</td>
<td>31</td>
</tr>
<tr>
<td>7.2. Main policy conclusions</td>
<td>33</td>
</tr>
<tr>
<td>8. Italy: building the Novamont ecosystem</td>
<td>34</td>
</tr>
<tr>
<td>8.1. The ecosystem(s)</td>
<td>34</td>
</tr>
<tr>
<td>8.2. Main policy conclusions</td>
<td>35</td>
</tr>
<tr>
<td>9. Japan: biomass towns and biomass industrial cities</td>
<td>37</td>
</tr>
<tr>
<td>9.1. The ecosystem(s)</td>
<td>37</td>
</tr>
<tr>
<td>9.2. Main policy conclusions</td>
<td>38</td>
</tr>
<tr>
<td>10. Norway: value chains based on carbon waste gases and marine residuals</td>
<td>40</td>
</tr>
<tr>
<td>10.1. The ecosystem(s)</td>
<td>40</td>
</tr>
<tr>
<td>10.2. Main policy conclusions</td>
<td>42</td>
</tr>
</tbody>
</table>
11. Sweden: a focus on biorefining for fuel production .......................................................... 44
   11.1. The ecosystem(s) .......................................................................................................... 44
   11.2. Main policy conclusions ............................................................................................. 46

12. The United States: building a biotechnology-based bioeconomy ...................................... 47
   12.1. The ecosystem ............................................................................................................. 47
   12.2. Main policy conclusions ............................................................................................. 49

13. Analysis of cases .................................................................................................................. 51
   13.1. A systemic approach to value chain and ecosystem policy analysis ............................. 51
   13.2. The balance of supply- and demand-side measures ..................................................... 52
   13.3. Policy alignment .......................................................................................................... 54
   13.4. The key role of demonstrator plants ............................................................................ 58
   13.5. The roles of public funding in clusters and other PPPs ................................................ 59
   13.6. The roles of modern biotechnologies and their alliance with computing and information technologies .................................................................................................................. 63
   13.7. Where are the medium-sized companies? .................................................................. 64
   13.8. Skills and education, essential to maintaining vibrant ecosystems .............................. 64
   13.9. High biomass diversity, relatively low product diversity .............................................. 65

14. Digital and experimental approaches to ecosystems policy at three geographical levels ...... 67
   14.1. Institutional level: Open Science at Neuro, Montreal .................................................. 67
   14.2. National level: the UK knowledge transfer networks (KTNs) ....................................... 67
   14.3. An international example: BSR Stars S3 .................................................................. 68
   14.4. Summary ..................................................................................................................... 69

15. Concluding remarks ............................................................................................................ 70

References .................................................................................................................................. 71
Endnotes ..................................................................................................................................... 74
Executive summary

Building regional and national bioeconomies is proving to be difficult. Joining them to make an international (circular) bioeconomy will require a major transition for society, away from fossil dependence and towards a more sustainable economy and future. The mix of policies that is required reflects both the complexity and the importance of this transition.

At the heart of the bioeconomy is the idea of small to medium-sized production facilities set in a location close to feedstock and conforming with the concept of distributed manufacturing. The manufacturing facilities themselves come in a variety of models. Their construction, in particular first generation (non-cellulosic), is almost a formulaic exercise in engineering; there are hundreds in Brazil alone. Far more difficult, however, is enabling an ecosystem of stakeholders, from the feedstock owners and producers, to the customers for bio-based products and on towards end-of-life/recycling.

Many countries are struggling with how to create both sustainable and commercially viable value chains and related innovation ecosystems. While some countries are having more success than others, there is little analysis to understand exactly how and why success can be achieved and what role policies could play. Complicating analysis is the fact that bioeconomies are so different depending on regional factors such as availability of forest and agricultural products and residues, domestic waste collection and disposal, local infrastructure and even public attitudes.

This current work examines how different countries are approaching innovation ecosystems in public policy. Ten different countries contributed case studies, spanning a geography from very specific locations (according to availability of feedstocks) to entire towns and cities. These various case studies revealed commonalities of experience despite a diverse array of drivers for bioeconomy development.

Some key findings are summarised as follows. The examples below are meant to be indicative and not exclusive to the mentioned country or countries.

- Bioeconomy is an opportunity to create jobs and wealth and to revitalise flagging industry sectors e.g. Belgium, Canada, France, Italy, and United States.
- Whole-of-government action and coordination across relevant agencies is especially important, e.g. United States, and essential for transition management.
- Policy consistency over long periods of time is essential e.g. Norway, Sweden.
- More targeted instruments and actions are now necessary e.g. Belgium, China, Norway.
- Early engagement with regulators prevents later barriers and lock-ins e.g. China, Norway, United States.
- Public-private partnerships are powerful and should serve a broad range of stakeholders e.g. Norway, United States. Funding clusters in various forms is very common e.g. Belgium, France, Italy. However, it is difficult for policy makers to assess their efficacy.
- It is important to strengthen the interplay between the traditional bioeconomy and advanced bioeconomy e.g. Canada, United States.
• Engineering biology and computing and ITs serve not only as drivers for the advanced bioeconomy, but as the hubs of ecosystems e.g. United States.

• There is a need for a better balance between technology push and market pull e.g. China, Italy, United States.

• It is possible to progress by taking advantage of a home market e.g. Italy, Norway, to build the distributed manufacturing business model e.g. Finland, France, Japan, Sweden, United States.

• More extensive economic research is needed on drivers such as high capital requirements and a lack of strategic customers e.g. Finland, Norway.

• Valorisation of wastes and residues is at the very heart of a circular bioeconomy e.g. all, very large scale in China.

• Caution is needed with interpretation of cascading use – valorisation for fuels and biogas rather than higher value-added can make more sense on occasions e.g. China.

• Measures are needed to correct a gap in some key technologies e.g. Finland, Norway.

• Measures are needed to correct a lack of demonstration facilities e.g. Belgium, Finland, France.

• Measures need to be identified to encourage growth of companies to medium-sized e.g. Finland.

• Utilising existing production infrastructure e.g. Sweden and former production infrastructure and brownfield sites e.g. Canada, Italy, can lower costs and barriers.

• Linking the circular bioeconomy to sustainability e.g. Belgium, Japan, Sweden, United States, and biodiversity protection e.g. Norway makes sure that the bioeconomy gains greater political visibility and serves a growing societal need.

• Life cycle analysis or a broader sustainability analysis should indicate if advantages of emissions reduction are negated by, for example, energy inputs e.g. Norway.

• In early phases of bioeconomy development urgent environmental concerns may override economics e.g. China.

• Education and training needs suggest a need for radical adaptations in the higher education sector e.g. Belgium, Canada, France, and Italy.

• Balance should be given between applied and fundamental research e.g. Canada, United States.

• Plastics have been catapulted to high political interest along with their replacement with bio-based plastics e.g. Belgium, Canada, Italy, Norway, United States.

• There is high importance and value in engaging the general public e.g. Italy, Japan, Sweden, especially with high priority issues such as plastics.

• The fossil resource-based society is so deeply entrenched that the policy mix will also need to contribute to a process of destabilisation of existing locked-in socio-technical systems.
1. Introduction

Modern economic growth is generated by a collection of sociotechnical systems based upon industrial mass production and individualized mass consumption that extensively employ fossil fuels, is resource and energy intensive and produces a massive amount of waste.


How can public policy help enable the necessary transition to a new economy that uses less energy, makes less waste, and inspires a more circular approach? Many countries see bioeconomy as a promising way forward. Envisaging a gradual replacement of fossil-based feedstocks with bio-based ones, the bioeconomy has emerged from a niche interest to the political mainstream with over 50 countries publishing dedicated policies and notices of intent. It has also grown from a biotechnology-based vision to an economic activity that spreads across several key sectors and policy families: agriculture and forestry, fisheries, food, trade, waste management and industry.

If a bioeconomy is to participate in an historic transition akin to the transitions from wood to coal and coal to oil, then there is an opportunity now, unlike in those earlier transitions, to draw on a body of policy learning and theory on how to manage such transitions. Unlike past transitions, this one is driven by simultaneous social and environmental challenges such as the Sustainable Development Goals as well as more familiar drivers of growth and competitiveness.

Policy makers and scholars alike are increasingly framing science, technology and innovation policy to emphasise these socio-technical system changes (Schot and Steinmueller, 2018). The current study on innovation ecosystems of the bioeconomy begins from the standpoint of systems transitions as well the deep problem of sustainability at national and international levels.

1.1. Transitions

Within a well-established body of literature, a “transition” can be seen as a fundamental change of structure, culture and practices in a societal (sub-)system (e.g. Geels, 2002). The structural change includes physical infrastructure, economic infrastructure and institutions. Cultural change involves changes on the collective set of values, norms, perspectives and paradigms. Change in practices include routines and behaviour down to the level of the individual. From this, it will be clear why transitions represent such mountainous task.

In transition governance, consider the need to:

- create innovation spaces for radical innovation
- remove barriers for the transition
- challenge the market and mobilise society
- promote long-term thinking while executing short-term action.

Systemic change calls for policy making that allows both small and deep support. Vision has to be complemented with a strategy that can be converted to action. It requires action at multi-actor, multi-sector and multi-level, and geographically it is national, regional and local in its approach.
Both the bioeconomy and circular economy require a change in mind-set. Given that the most important sectors are in silos, there are efforts at decoupling required. Consider the magnitude of the efforts to decouple agriculture and the chemicals sector from the fossil economy. Even if there were to be minimal public acceptance issues, there would still be large vested interests to be addressed. Similarly, closing the loops to convert the linear to a circular economy requires disruption and radical change that will take decades to achieve. This new economy also needs new business models (OECD, 2018a).

Rotmans argues that the bioeconomy and circular economy are actually two out of three sub-transitions towards the overall goal of a transition to a new, green economy (Rotmans, 2017). They are in the pre-development phase of a transition. The phase indicators are that: the bioeconomy focus is still on bioenergy rather than the biorefinery that makes products of higher value-added than electricity and fuels; the bioeconomy is still dominated by small-scale bio-based businesses, even earlier in pre-development. To contribute to the goals of a green transition, then, requires acceleration.

**Box 1. Definitions**

**Bioeconomy.** Consistent with the OECD (2009) publication *The bioeconomy to 2030 – designing a policy agenda*, a working definition for the purposes of this report is the set of economic activities in which biotechnology and the life sciences (also chemistry and in particular their smart integration) contributes centrally to primary production and industry through the conversion of biomass into food, materials, chemicals and fuels. In the last decade, however, the bioeconomy concept has outgrown just 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.

**Circular economy.** There is no single accepted definition of a circular economy. The precise meaning of a “transition to a circular economy” varies across the current literature, but tends to involve reduced demand for certain natural resources, and the materials that are derived from them. The resources usually emphasised are minerals (both metallic and nonmetallic), fossil fuels, and various biotic resources such as forestry, fish, or other biomass. Relatively little attention tends to be given to other resources: land and water are the most obvious examples (OECD, 2018d). A circular economy is an economy in which resources are kept in use for as long as possible to extract the maximum value, and is a distinct alternative to a traditional linear economy (make, use, dispose). At the end of service life, materials should be recovered instead of disposed of. In other words, resource efficiency and waste minimisation are key objectives for a circular economy (OECD, 2018c).

1.1.1. How can a transition be accelerated?

Previous transitions and surges required many decades. There are strong arguments that there is not enough time to allow this to happen now, given the magnitude of the challenges being faced by society. Therefore, policy makers must examine ways of accelerating the transition, which is likely to be fiercely competitive and far from smooth. There is no set recipe for this. Complicating analysis is the fact that bioeconomies are so different depending on regional factors such as availability of forest and agricultural products and residues, domestic waste collection and disposal, local infrastructure and even public attitudes. At least 25 juridical barriers for the new economy were identified in the
Netherlands alone, some operational, some structural and some fundamental. For example, a structural barrier exists in using wastes or residues as a feedstock or resource (Bosman and Rotmans, 2016), a barrier not unique to the Netherlands but quite common in Europe.

Most literature with the systems of innovation approach focuses on how to optimise the organisational and institutional systems that support innovation, but transition scholars provide insights into how to handle this transformation from a more pragmatic point of view. They propose a so-called multi-level perspective to stress that transitions require changes at the level of the broader landscape for innovation, in the institutional and regulatory regimes of sectors, as well as changes within the sectors themselves through entrepreneurial actors (Geels, 2002).

According to some accounts, transition management can be practiced in four major steps, all of which aim to foster experimentation and facilitate the emergence of new niches by entrepreneurial activities of frontrunners.

1. Define and structure the transition aimed for (for example related to the transition to a bioeconomy) and define the challenge or socio-technical goal that is to be achieved.

2. Develop a joint agenda and roadmaps to achieve the socio-technical goals (for example specificities in the transition to the bioeconomy).

3. Engage in experimental innovative activities in line with the roadmap to reach the goals. Often these emerging networks, value chains or innovation ecosystems, may experience infighting and conflicts about the pace and direction of changes.

4. Continuously monitor and evaluate transition experiments and pathways to ensure reflexivity, openness and continuous adjustments. (Loorbach and Rotmans, 2010).

1.1.2. The role of technology surges

Technological shifts are a major driver of transitions, and some see such shifts occurring due to technological convergence and increasing needs for resource efficiency. If the start point assumed is around 1770, Perez (2002) recognised five technological surges, each lasting around 40-60 years. The last of these is information and telecommunications, an ongoing transition set in motion around the start of the 1970s with the arrival of inexpensive commodity electronics.

Schot and Kanger (2018) see “computer-aided biotechnology and new materials” within the context of the ongoing information and telecommunications surge. However, they also envision the sixth surge, which is already underway, characterised by renewables as the dominant energy paradigm, and having the following characteristics:

- decentralised generation of power, from multiple energy sources
- competitive international trade in renewable electric power
- reduced energy intensity and enhanced efficiency (e.g. through operations of energy services companies)
- intelligent (smart) IT-enabled grids for distribution of renewable electric power, giving resilience to power networks
- biomimetic organisational and industrial design principles
- circulation of resources and resource efficiency – the circular economy
The bioeconomy can be seen as either a transition in itself or part of the sixth surge in which computer-aided biotechnology uses renewable feedstocks to make drop-in or new materials and fuels, with an orientation to sustainability and circularity, and a bulwark against fossil resource depletion.

1.2. The promise of an innovation ecosystems approach

Following Kanter (1994), this study defines innovation ecosystems as “groupings of companies in different industries with different but complementary skills which link their capabilities to create value for ultimate users.” The emergence of new types of value chains and innovation ecosystems related to opportunities across firms, sectors and countries can eventually support the bioeconomy transitions (for a general overview see Hansen and Coenen (2015); for a biorefinery-specific example see Hellsmark et al. (2016)).

Attention to innovation ecosystems grows out of both a commitment to the idea of transitions management and the sustainability development challenge. It is a concept very similar to that of value-chains but it also includes the idea that value chains may converge and develop into cross-industrial networks where a broader range of also horizontally related actors create value to each other, e.g. through industrial symbiosis/circular economy solutions.

The literature on emerging technological innovation systems can be helpful for understanding generalised functional drivers, and differences therein. Extensive empirical work on emerging technologies and innovation ecosystems across a broad range of countries has identified seven such drivers:

1. entrepreneurial activities in terms of experiments and demonstrations
2. knowledge development involving learning activities, mostly on the emerging technology, but also on markets, networks, users and other;
3. knowledge exchange through networks and across value chains
4. guidance of the search including individual choices related to the technology but also in terms institutions e.g. related to policy target
5. market formation involving activities that contribute to the creation of a demand for the emerging technology e.g. taxation, procurement
6. resource mobilisation, or the allocation of financial, material and human capital, and
7. support from advocacy coalitions to promote new technologies and innovations.

These insights can be applied to the bioeconomy. There, large investments in biorefineries can become stranded if diverse supply and value chains cannot be developed to fully optimise these investments. In addition, these value chains would need to be sufficiently both vertically and also horizontally interlinked across sectors so that closed loop production could be achieved in a sustainable and profitable way through new types of innovation ecosystems. Joining up these sectors is in line with broader policy thinking related to the circular economy, including at the European level (e.g. BBI JU, 2016; European Bioeconomy Stakeholders Manifesto, 2016).
1.3. Primary study questions

Building a biorefinery is an almost formulaic exercise in engineering. Far more difficult is developing the industrial and innovation ecosystem of stakeholders needed from feedstocks to final products and beyond to end-of-life and recycling. This could be said to achieve the goals of a so-called circular bioeconomy (CBE) (OECD, 2018c). Arguably, this is exactly what is needed to make a transition to a more sustainable distributed manufacturing model, as envisaged for CBE, and to create jobs and wealth locally.

Many countries are struggling with how to create both sustainable and commercially viable value chains and related innovation ecosystems (Philp et al., 2017). While some countries are having more success than others, there is little analysis to understand exactly how and why success can be achieved and what role policies could play. Complicating analysis is the fact that bioeconomies are so different depending on regional factors such as availability of forest and agricultural products and residues, domestic waste collection and disposal, local infrastructure and even public attitudes.

This project aims to support innovative bioeconomy policies across OECD countries by addressing the following two over-arching questions.

- Which types of policies would help to spur technological development and the formation of new types of cross-sectoral value chains, industrial and innovation ecosystems and commercial partnerships to enable the transition to a more sustainable and circular bioeconomy?

- How might these policies and arrangements differ across different types of bioeconomies in terms of the types of biomass, nature of innovation systems and structure of biomass-utilising industries?

Much can be learned from experiments in the circular bioeconomy, and bioeconomy writ large, across countries. These examples illustrate the complexity of bioeconomy systems but highlight levers that might be available to policy makers as they help realise models of sustainable innovation in their countries.

1.4. Key findings of the study

1.4.1. Diverse goals for building circular bioeconomy ecosystems

Policies and strategies for a circular bioeconomy should make a statement of intent regarding national ambitions. Usually there is more than one in each country. If climate change is a driver, then this signals high ambition and therefore the commitment from the top of government should be evident. It is very difficult to deploy a new technology based solely on environmental credentials; the economic case has to be sound as well. Therefore the drivers for each nation should reflect this as a reality of developing a circular economy.

Divers that were mentioned by countries include:

- climate change and climate obligations (most countries)
- lowering/ending oil dependence (especially Sweden)
- rural development/regeneration/reindustrialisation (especially China)
- brownfield redevelopment/revitalising chemical industry (especially Canada and Italy)
• resource efficiency (all countries)
• waste and its valorisation (most case studies, especially China).

There were some drivers that were certainly more country-specific. For example, Finland is using the circular bioeconomy to drive more efficient use and value-added from forestry. Japan has additional concerns around natural disaster resilience.

### 1.4.2. High biomass diversity, lower product diversity

Compared to even five years ago, biomass feedstocks are diversifying. In the case studies below, they cover agricultural and forestry residues (e.g. straw, sawdust), wood, food waste, food crops (e.g. sugar beet), domestic waste, marine resources and waste industrial gases. An ongoing policy issue will be how to support waste collection. Wastes as feedstocks brings a circular element to the bioeconomy, but in some countries there are ongoing regulatory barriers to doing so.

In terms of products, some countries have a focus on bioenergy, biofuels (ethanol, biogas, biodiesel and biojet fuel) and district heating. Higher added-value products are less common, although by no means absent. Textiles, bioplastics and biocomposites are relatively common. What can be described as ‘intermediate value fossil drop-ins’ are missing. Materials such as bio-based ethylene and propylene, while offering the potential for large greenhouse gas (GHG) emissions savings, are difficult due to cost competition from the fossil equivalents. Therefore, companies seek to find different molecules with similar characteristics to the typical petrochemicals that dominate the market. In the circular economy, however, they would find great difficulty entering recycling streams.

Again this should signal national intention. If using a circular bioeconomy as a tool in climate change mitigation, then it is important that the product profiles service that ambition. Very low-volume, high-value bio-based products could service an ambition for, say, reindustrialisation, but contributions to GHG emissions savings would be minimal.

### 1.4.3. A systemic approach to value chain and ecosystem policy analysis

Many new value chains in the emerging bioeconomy suffer from what may be described as a “systemic challenge”. The key problem in such cases is that no part of the value chain is viable on its own accord, but depends on the success of the other parts in a systemic manner. Typically, this is seen when combining a novel, poorly characterised feedstock with a relatively immature conversion technology, in order to meet an unestablished customer need. The chain is only as strong as its weakest link. A way forward is public-private concerted action, involving coordinated innovation efforts and supportive policies throughout the whole chain.

### 1.4.4. Alignment

In a related point, achieving complex goals like transitioning a production and energy system away from fossil-based ones requires systemic thinking: many interrelated sectors, policies and technologies will be implicated. In these circumstances, policy alignment becomes a critical theme in at least three dimensions: First, bioeconomy policies should align with policies on the circular economy and broader industrial policy around the issues of waste and the cascading use of biomass. For example, in order to mitigate competitions over biomass, policy might aim to support larger ecosystems based on organic materials that are less perishable (such as wood-based materials or that reduce the perishability of
organic side streams). Reforms in Europe and other jurisdictions to regulations on waste and landfills can render the use of biomass more efficient.

Second, transitions require whole government effort to align relevant policy areas such as R&D and industrial policy (OECD, 2015). Some cases such as Sweden suggest that failure to connect up a R&D policy agenda with industrial policy can lead to failures to embed biorefinery PPPs within diverse supply and value chains. Third, government agencies need to be coordinated at both a micro and macro level. In particular, there is the danger of agencies and departments involved in technology push (e.g. innovation agencies) being at crossed purposes with those involved with market-pull.

1.4.5. A lack of demand-side, market-building instruments

Governments traditionally are wary of advancing instruments that affect or distort markets, thus there is preponderance of supply-side policies in the bioeconomy. However, a shift to a bio-based economy will likely require a balance of more demand-side measures in order to help ensure a market for innovative products that have taken much public funding to bring from idea to reality. In the green shift (or emerging bioeconomy) it may be necessary to generate a societal pull preceding a market pull, and hence a balance. In Box 3 on the systemic policy challenge, a lack of attention to this balance shows how policy may fail to advance the market need.

1.4.6. Consistently featured policy instruments

Clusters dominate: Publicly funded technology, regional and biomass clusters are still popular instruments. Building circular bioeconomy ecosystems entails the very difficult task of making disparate industry sectors network with each other to identify business opportunities. The clusters fulfil this role by reducing the transaction and opportunity costs of bringing people together. Flanders illustrated the case for building international clusters, and the potential benefits of internationalising are discussed.

Pilot and demonstration phase funding: This has always been one of the top policy issues and will continue to be so. The demonstration phase is seen as being essential, but is also very high risk. The private sector looks to the public sector to de-risk the large investments needed. Norway has shown that small, wealthy nations can have critical gaps, e.g. related to technology or skills when they set out to develop new value chains without a local tradition. Funding demonstration scale can help to fill the gaps by attracting foreign technology providers and/or encourage the growth of these companies domestically.

Joining policy up: Policy in Japan shows clear attempts to build whole communities through different policy incentives, in which a goal would be for communities to be more energy self-sufficient as well as creating local value-added bio-based industries. While looking at the synergies, one of the difficulties of joining up policy is to prevent making unintentional barriers. A very obvious and real case would be using supply-side policy instruments to encourage using wastes as feedstocks while there are regulatory barriers to doing so, and ignoring market-making incentives for the finished products.

Carbon price and taxation: Given the importance of climate obligations, little attention is paid to carbon price and taxation. Sweden and Norway are notable exceptions. While climate policy and fossil resource replacement remain as significant drivers, carbon price and taxation present great opportunities for governments to finance instruments of the CBE.
1.4.7. Where are the medium-sized companies?

Much policy attention focuses on small companies when SMEs are discussed. Medium-sized companies that can contribute to both R&D and manufacturing are pivotal in manufacturing sectors such as automotive, but they are not yet common in the bioeconomy. A topic for future research might be how to grow from small- to medium-sized, for at least one very good reason: when large companies wish to partner to build their ecosystems, medium-sized companies are likely to have greater financial security than small or micro enterprises. This is especially so if those small enterprises are high-risk R&D companies with a small IP portfolio and a promising technology, but with few or no products.

1.4.8. The role of biotechnology, computing and IT convergence

In some OECD Member States small industrial biotechnology companies are missing and the technology has to be imported from abroad. If countries need these modern biotechnology companies in their bioeconomy but have to look abroad for them, then there are questions for policy makers in R&D&I. Are the investment conditions wrong? What specific conditions are necessary to allow innovative yet high-risk biotechnology start-ups to survive? What is their relation to the greater goals of a bioeconomy, such as climate change mitigation?
2. Methodology

2.1. Qualitative case studies across countries

As stated above, it was decided that comparative country case studies of a qualitative nature would be optimal for achieving a more nuanced understanding of innovation ecosystems as a general phenomenon. A template with common research questions was developed with members of the Working Party as well as invited experts. The template featured sets of questions grouped under three headings:

- The biomass-utilising values chain
- Extension of the value chain towards cross-industrial networks/ecosystems
- Broader country priorities and role of policies in the case study.

These headings, with a set of questions under each, formed the template, which is reproduced below in Table 1.

Table 1. Questions to be addressed by the qualitative case study interviews.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Interview questions</th>
<th>Actor to be interviewed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The biomass-utilising value chain</td>
<td>What types of biomass are envisaged as the priority feedstocks, and is this unusual relative to other enterprises in your country?</td>
<td>Company, PPP</td>
</tr>
<tr>
<td></td>
<td>In your sphere of operations, who are the main suppliers of biomass, and what are the challenges in supply?</td>
<td>Company, PPP</td>
</tr>
<tr>
<td></td>
<td>Which type of refining technique(s) are to be used or are being used?</td>
<td>Company, Research organisation, PPP</td>
</tr>
<tr>
<td></td>
<td>In your region, is it easy or difficult to find employees with suitable qualifications and experience for these operations?</td>
<td>Company, PPP</td>
</tr>
<tr>
<td></td>
<td>What types of products/processes/services are being developed?</td>
<td>Company, PPP</td>
</tr>
<tr>
<td></td>
<td>Can you give examples of end-user industries for these products/processes/services?</td>
<td>End-user company, PPP</td>
</tr>
<tr>
<td></td>
<td>What are the greatest challenges related to operating the current biomass utilising value chain?</td>
<td>Company, Research organisation, PPP</td>
</tr>
<tr>
<td></td>
<td>What are the greatest opportunities related to operating the current biomass utilising value chain?</td>
<td>Company, Research organisation, PPP</td>
</tr>
<tr>
<td>2. Extension of value chain towards cross-industrial networks/industrial ecosystems</td>
<td>Is there potential for utilising biomass across a broader set of end-user industries?</td>
<td>Company, PPP</td>
</tr>
<tr>
<td></td>
<td>What kinds of knowledge and knowledge networks will be necessary to extend the value chain?</td>
<td>Company, PPP</td>
</tr>
<tr>
<td></td>
<td>Do you have examples of ongoing biomass refining/utilisation experiments, ventures, demonstrations for new products/processes/services?</td>
<td>Company, PPP</td>
</tr>
<tr>
<td></td>
<td>What are the economic impacts of these new products/processes/services compared to a current/previous vertical value chain?</td>
<td>Company, PPP</td>
</tr>
<tr>
<td></td>
<td>What are the estimated sustainability impacts of these new products/processes/services compared to a current/previous vertical value chain, and how are sustainability impacts assessed?</td>
<td>Company, Research organisation, PPP</td>
</tr>
</tbody>
</table>
### What is/will be the impact of circular economy solutions for extended current value chains?
Company, PPP

### Can you give examples of new partners and other stakeholders that are needed to extend current value chains?
Company, RDI funding agency, PPP, Standard and certification organisation

### Can you give examples of the need for new business models related to extending vertical value chains?
Company, PPP

### How do these new business models differ from previous business models?
Company, PPP

### What criteria do you use when selecting new partners for your industrial ecosystem?
Company, PPP

### What is the most useful thing that the public sector can do to improve your industrial ecosystem building?
Company, PPP

### Is there any regulatory hurdle to you developing your business further?
Company

### Are there any issues we have missed that you feel are critical to the exercise?
Company, RDI funding agency, PPP, Standard and certification organisation

### 3. Broader country priorities and role of policies in the case study

<table>
<thead>
<tr>
<th>Question</th>
<th>Responsible Parties</th>
</tr>
</thead>
<tbody>
<tr>
<td>What are your country priorities and broader drivers for transition to a bio- and circular economy?</td>
<td>RDI funding agency and host ministries, Policy makers</td>
</tr>
<tr>
<td>What are the primary policy documents for your government to pursue bio- and circular economies?</td>
<td>RDI funding agency and host ministries, Policy maker</td>
</tr>
<tr>
<td>Can you give examples of ways in which policies, agencies and their specific funding or other instruments have advanced the case study example?</td>
<td>RDI funding agency and host ministries, Policy maker</td>
</tr>
<tr>
<td>Can you give examples of ways in which policies, agencies and their specific funding or other instruments have advanced the creation of cross-industrial networks and innovation ecosystems in the case study example?</td>
<td>RDI funding agency and host ministries, Policy maker</td>
</tr>
<tr>
<td>Are there regulatory and/or institutional enablers or barriers in this particular case?</td>
<td>RDI funding agency and host ministries, Policy maker</td>
</tr>
<tr>
<td>What are the challenges for policy in extending current value chains towards cross-industrial networks and innovation ecosystems/new business models?</td>
<td>RDI funding agency and host ministries, Policy maker</td>
</tr>
<tr>
<td>What are the opportunities for policy in extending current value chains towards cross-industrial networks and innovation ecosystems/new business models?</td>
<td>RDI funding agency and host ministries, Policy maker</td>
</tr>
<tr>
<td>Which level of government is best equipped to lead in policy?</td>
<td>RDI funding agency host ministries, Policy maker</td>
</tr>
</tbody>
</table>

### 2.2. Case study selection criteria

In order for the case studies to contribute to existing understandings and enrich insights of existing reports and surveys it was proposed that participating countries select two or more specific emerging value chain/innovation ecosystems, related to the use of specific biomass for new products in higher value-added sectors.

Country delegates were given a set of positive selection factors to guide the choice of key sites and value chains for the study. These criteria included:

- industrial activities that cross value chains and are maturing into a business-driven innovation ecosystem
- important type of biomass in country and utilisation sector globally
- innovation ecosystem that relates to policy action
• innovation ecosystem that covers both research actors and companies
• innovation ecosystem that exemplifies how circular economy ideas can be utilised for developing the bioeconomy from a sustainability or other perspective
• accessibility in terms of data collection
• demonstrates both opportunities and challenges.

It is worth stating here that ultimately the case studies show great variety in their geography. Norway honed in on two very specific case studies with feedstocks that would signify specific territories (in these cases – access to waste industrial gases and marine biowaste). The Sweden case study looked at bio-based manufacturing at different locations. The Italy case shows how one company (Novamont) has built national infrastructure and its own ecosystems. At the other end of the scale, China has an ecosystem for utilising straw that spans most of the country. The case of France is based on a private sector biorefinery that is truly set in a rural location. At the extreme end, the Japanese case is about creating ecosystems of entire towns and communities. The United States case study focuses on engineering biology and public biofoundries as a platform for building the bioeconomy.

2.3. What follows: summaries of the case studies

The rest of this paper summarises the value chains and the main findings from the case studies, with specific materials taken from the various workshops that supported the project. A preliminary analysis of eight of the case studies was presented at an OECD workshop in Rimini, Italy, on November 07, 2018. The full cases are contained in an Annex to this report and can be found at www.oecd.org/sti/emerging-tech/innovation-ecosystems-in-the-bioeconomy-annex.pdf.
3. Belgium (Flanders): a summary of regional ecosystems

The case study from Flanders does not focus on a single ecosystem; rather it more resembled a summary of the ecosystems of the region. What will be evident is ambitions to use a large range of different feedstocks that would typify a circular bioeconomy, from pure sugar to organic waste and waste industrial gases.

3.1. The ecosystem(s)

3.1.1. Transformation of organic waste matter to bio-based chemical products and primary sources for industrial production

This is considered to have high potential for returns in the short term, and much effort has been focused here. The market expectations are that organic waste will continue to be produced, and higher valorisation options are the best way to deal with these waste streams. This material revalorisation can provide, for instance, fibres for building materials and feed or alternative fillers for plastic or composite materials. By dissociating organic waste streams into components, multiple waste streams are created that can be targeted to different revalorisation processes. The strategy provides for local and decentralised waste collection and transformation that may provide larger local benefits.

3.1.2. Production of specialty chemicals from sugars and starch and other renewable sources

The production of specialty chemicals is a trend that is expected to continue to grow with the growth of industrial interest. At the same time the sugar supply is expected to grow, because the European production quota have been recently abolished, and sugar contents in food are declining. Moreover, the Belgian agricultural sector has a large experience and tradition in sugar production.

3.1.3. Production and use of second generation sugars as a base for industrial biotechnology and green chemistry

This pathway focuses on the reconversion of cellulose in waste streams. By transforming cellulose from waste streams from agriculture or manufacturing, the ecological impact of the bioeconomy can be further reduced. During the last five years, important technological breakthroughs have been achieved in chemo-catalytic transformations to produce valuable materials and chemicals from cellulose. Industrial and agricultural waste streams exist in Flanders with high cellulose content, providing the basis for successful business cases in the long run.

3.1.4. Conversion of waste gases to chemicals

The high level of industrialisation of Flanders provides numerous sources of waste gases that can be transformed by bio-based processes. Very recently the Arcelor Mittal steel mill has started a pioneering transformation to produce ethanol based on waste gases by fermentation. Similar processes and set-ups are under investigation by companies and research institutes.
A large diversity of actors is involved in these projects, ranging from large companies, innovative SMEs, research organisations and public authorities. There are a few crucial actors that structure the landscape. Universities, research organisations and two strategic research centres (ILVO and VITO) are all involved. Flemish authorities have implemented a policy of spearhead clusters and innovative business networks. These spearhead clusters can benefit from structural support and earmarked R&D budgets for industrial development and collaboration projects. As cluster organisations, they typically foster networking between its members (companies, government, knowledge and research institutes) and follow up and communicate on strategic sectorial trends and business intelligence. There are two such clusters relevant to the bioeconomy, Catalisti and Flanders Food.

Catalisti is the spearhead cluster of the chemical sector. Around 100 companies and all Flemish universities are partnering with Catalisti together with Essenscia Vlaanderen (sector federation for the chemical industry), VITO (Flemish Institute for Technology Research), Centexbel (research centre for the textile industry) and the Bio Base Europe Pilot Plant (independent pilot facility for the bio-based industry).

The innovation agenda of Catalisti is centred around four main innovation programmes: “Renewable Chemicals”, “Sidestream Valorisation”, “Process Intensification and Optimisation” and “Advanced Sustainable Products”. Within these innovation programmes, the cluster is working on the elaboration of the following strategic themes: Carbon Capture and Utilization (CCU), Bio-aromatics, Sugar as Feedstock, Plastics Conversion, Industry 4.0 and Circular Economy.

Flanders Food is the spearhead cluster for the agro-food business. It has two knowledge-driven strategic objectives (lead in knowledge and lead to knowledge) and two business-driven strategic objectives (accelerate efficient and effective innovation and cross/create value chains). The knowledge-driven strategic goals will focus on three programme lines: world class food production; resilient and sustainable agrifood systems and; personalised food products and healthy diets.

BioBase Europe Pilot Plant is an independent and combined pilot training facility that supports the development of sustainable, bio-based products such as biochemicals, bioplastics, biomaterials, biodetergents and bioenergy from renewable biomass resources. Its mission is to stimulate sustainable development and economic growth by facilitating R&D and training for bioprocessing. It consists of a pilot plant for the bio-based economy located in the port of Ghent (Belgium), and a training centre for the bio-based economy in Terneuzen (Netherlands). Both facilities are located in the cross-border Gent-Terneuzen harbour area.

Industrial clusters in Flanders, the southern part of the Netherlands and North Rhine Westfalia have formed the BIG-C smart specialisation initiative. BIG-C focuses on new value chains for bio-based aromatics, chemicals from CO and CO2, and aviation fuels from various feedstocks.

Biorizon was initiated by Dutch and Flemish independent research organisations with expertise in clean technology and sustainable development. At the core of Biorizon stands technology development for the production of bio-based bulk aromatics (BTX) and functionalised bio-based aromatics for performance materials, chemicals and coatings.

The EU Smart Specialisation Vanguard initiative includes the Bioeconomy pilot with two ‘cases’ that are the heart of this TSSP project: ‘bio-based aromatics’ and ‘waste gas conversion’. Participating regions include Emilia Romagna, Flanders, Lower Austria, Navarra, NRW and South-Netherlands and Wallonia.
Biobase Europe started in 2008 as a cross-border Flemish-Dutch initiative and has since then always kept a strong international focus. At present companies from all over the EU and from elsewhere in the world come to Ghent to scale-up and pilot their own research and/or products.

### 3.2. Main policy conclusions

The main conclusion is that generic policy instruments are not applicable any more as the diversity of solutions and technologies increases sharply. More targeted instruments and actions are necessary, requiring a more flexible policy framework. At the same time, closer interaction between policy makers and local stakeholders has to be created. This interaction should enable all stakeholders to identify the emerging niches in the sector, and to design targeted actions to enable their development.

The sector should investigate options to structure itself more coherently. A better network can provide visibility, increased synergies and faster development. Also international partners may be better guided by a central structure in order to speed up international collaboration and project proposals.
4. Canada: the Sarnia-Lambton cluster

Creating a bio-based and circular economy in Canada is driven by the goals to meet climate change limits and develop new and innovative economies in the country. Demonstrated by the signing of the Paris Agreement and through national level action plans, Canada is starting to change the systems currently used in the country.

The Sarnia-Lambton Hybrid Chemistry Cluster began as an evolution of the traditional petrochemical industry. Knowing that diversification of the area was necessary so that growth would continue, Bio-industrial Innovation Canada\(^1\) (BIC) was formed to facilitate this change. As a government funded non-profit organisation, BIC is well positioned to provide critical investment, advice and services to early-stage companies with clean, green and sustainable technologies. This case study focused on the role that BIC and other partners played in growing the Sarnia-Lambton Hybrid Chemistry Cluster.

4.1. The ecosystem(s)

Petrochemical companies in the region have a long history of collaboration as they partner with colleges and universities around Sarnia-Lambton for access to more highly qualified personnel.

Factors drawing companies to the Sarnia area, include:

- existing infrastructure at TransAlta, Arlanxeo, and other sites
- the highly qualified personnel and training potentials
- the network of contractors, consulting agencies, and logistics coordinators.

The first company to start the shift from petrochemicals to bio-based products was Suncor with the construction of their 400 million litre per year first generation ethanol plant in Sarnia-Lambton. Constructed in 2006, Suncor Ethanol uses 20% of the Ontario corn crop to produce ethanol for petrol (gasoline) blending.

In 2015, BioAmber\(^2\) selected Sarnia-Lambton for the location of its first commercial production facility to produce a bio-based product that could compete in the market with oil-based succinic acid. Supply of glucose to BioAmber was identified as a gap in the supply chain and a business case study was developed to build a supply system. The use of cornstalks and other crop residues from the Sarnia-Lambton area as the feedstock for the bio-industrial production of cellulosic sugar was examined as well as the impact and viability of the collection of crop residues from farms.

Having established the sufficiency of locally available materials, the Cellulosic Sugar Producers Cooperative (CSPC) was formed and the selection process for a technology provider was started. Nineteen potential technologies were identified, and careful examination and study of each company was performed. Comet Biorefining was selected as the preferred partner by the CSPC based on recommendation from BIC. Comet is currently set to become the third bio-industrial process constructed in Sarnia-Lambton. The Comet process uses enzymatic hydrolysis to convert corn stover provided by the CSPC to glucose, hemicellulose, and lignin products. Glucose is the primary focus of Comet, being the highest value product and most versatile. They are developing applications for lignin as well. Members of the Sarnia-Lambton Hybrid Chemistry Cluster use glucose in
fermentation reactors, such as BioAmber, Suncor Ethanol, Greenfield Ethanol, and IGPC Ethanol.

More supply chains have also started emerging in the cluster since the announcement of Comet and the CSPC. Origin Materials is also using cellulosic biomass as a feedstock and could work with the CSPC as another off-taker of farm residue. Their technology also has the flexibility to use wood products and so can be fed from multiple markets. Origin will also be the first company in the Sarnia cluster to produce advanced biochemical intermediates that can be used to produce Polyethylene terephthalate (PET).

Further farm-based sugar supply is being investigated by the Ontario Innovative Sugarbeet Processers Cooperative (OISPC). The proposed cooperative would grow 30,000 acres of sugar beet crops, build a processing facility for sugar conversion, and sell the sugars directly to chemical conversion processes.

Transalta, which own and operate a 500 MW steam turbine power station, and Arlanxeo, a producer of butyl rubber, have been vital to expansion, offering start-up companies land and facilities for construction of first-of-kind production facilities. Having this infrastructure available removes barriers for these companies and repurposes land and resources that were under-utilised. Construction on brownfield land can reduce mobilisation and capital costs for start-ups, and access to behind-the-fence utility costs lower operating costs.

A critical component of building successful clusters is training and maintaining highly qualified personnel and the advancement of science and technology. Western University was an integral partner to enable the creation and successful implementation of the BIC Centre of Excellence for Commercialization and Research (CECR). Since then, Lambton College has partnered with BIC in the Sarnia-Lambton Hybrid Chemistry Cluster to provide applied research and development capability through its five research centres of excellence that cluster companies leverage to reduce barriers to commercialisation.

With two constructed commercial plants, three planned commercial plants, and many interested parties at a variety of stages ranging from concept to pilot, Sarnia-Lambton has become a centre for collaboration and innovation of industrial products. The key pieces leading to this are the availability of feedstock, either biological or chemical, industry collaboration, and existing infrastructure, supported by a range of public policies.

Sarnia-Lambton has the entire infrastructure required to help new companies streamline their start-up process. With brownfield land available that has close connection to water, power, natural gas, steam and water treatment, it is much easier to establish a plant compared to greenfield construction. These and other factors, have positioned Sarnia-Lambton as a high-growth location for the bioeconomy.

4.2. Main policy conclusions

An interesting distinction is made between what is termed the “advanced bioeconomy” to distinguish from traditional bioeconomy practices such as agriculture, forestry, and marine products. Canada is beginning to focus on creating a circular economy to move towards waste-free societies. The ecosystem at Sarnia-Lambton reflects all three facets of traditional bioeconomy (e.g. acquisition of biomass), advanced bioeconomy (e.g. BioAmber) and circularity.

A landmark in policy has been the creation of Bio-industrial Innovation Canada in Sarnia, formed to facilitate industrial collaboration and help remove barriers to commercialisation.
for early stage companies. Industry collaboration was seen as an important step in creating a viable ecosystem for new companies to grow through providing funds, and for the existing companies to diversify their business interests. (It has often been noted in other countries that there are few medium-sized bioeconomy-dedicated companies; therefore there are likely to be common factors limiting the ability of early-stage companies to grow). Success at Sarnia is to be continued by the planned creation of two new clusters by BIC starting in 2019.

On the national arena, Canada is working towards a national comprehensive bioeconomy strategy. National initiatives have been developed, supported by federal players. It is expected that work on these will transition to a national strategy eventually to the creation of a national framework.
5. China: abundant agricultural residues as feedstock

In the 13th Five-Year Plan (FYP) on bio-industry development issued by the National Development and Reform Commission (NDRC) in 2017, it is stated that by 2020, the scale of the bio-industry will reach CNY 8 to 10 trillion, and the added value of the bio-industry will account for more than 4% of GDP. It is anticipated to become the leading industry of the national economy.

Innovation in agriculture and food production remains a key priority. In the area of bioenergy, the focus is on promoting non-food biomass for electricity, biofuels and heating. The strategy plans further emphasise the promotion of environmental and recycling technologies to improve water and soil quality, foster circular production, reduce carbon emissions and protect biodiversity.

5.1. The ecosystem(s)

According to data published by the National Bureau of Statistics of China, crop straw in China is mainly corn stalks, rice straw and wheat straw. In 2015, discarding or burning 19.9% of available straw (some 151 million tons) resulted in severe air pollution, potential safety hazards, and waste of biomass. Technology for the production of methane and bio-natural gas (BNG) from straw with anaerobic fermentation as the core has been deemed an effective approach for processing straw and generating bioenergy.

From 2015-2017, the central government invested a total of about CNY 2.7 billion to support the construction of 65 large BNG projects. The methane produced by the projects was purified and then sent into the natural gas pipe network, or used as vehicle fuel, or gas for businesses or residential use. Fermented BNG residue and BNG slurry were used to produce organic fertilizer, which was applied in farmland for production of crops. In this way, these three functions, namely control of environmental pollution by straw, production of renewable clean energy and organic fertilizer, were fulfilled in one process. This production system involves biological fermentation, bioenergy and bio-fertilizer and is a representative of the “biological circular economy” (Figure 1).
Chifeng in Inner Mongolia is an important corn-producing region. To cope with stalk processing and utilisation, Chifeng Yuanyi Biogas Technology Co., Ltd invested and developed a large-scale project (Ar Banner Project) for the ecological recycling and utilisation of BNG and organic fertilizer from straw. The company promotes large-scale, commercial, standardised and modular integration according to the “three-in-one” technology roadmap of agricultural waste, clean energy and organic fertilizer.

For constructing and popularising a complete ecological cycle value chain system, multiple organisations need to cooperate closely including those engaged in technological research and development, investment and construction, and departments of central or local governments. The main stakeholders involved in China include a large number of technology and research and development organisations, government departments and investment, engineering, construction and operation companies spanning the entire country.

There is large scope for developing the system further. With the rapid social and economic development, and rising living standard in China, there is an increasing number of wastes. At present, China generates 1.04 billion tons of crop straw, 2.05 billion tons of animal manure, 260 million tons of fruit and vegetable waste, 210 million tons of waste from processing industry for agricultural products, about 80 million tons of rural organic rubbish and 164 million tons of urban organic household rubbish every year, which totals some 3.804 billion tons.

5.2. Main policy conclusions

The ‘straw bioeconomy’ is regarded as highly value-added, the long waste recycle chain is in strong demand in the market and it has strong potential to generate new business opportunities and modes.

Still a variety of challenges face the value chain. As regularly seen with bio-based products, BNG profitability is low and cannot compete with conventional natural gas. Gaining access
for BNG to national pipelines requires policy action. The situation suggests a quota system, or even a hybrid form of feed-in tariff (FIT) that is used for gaining renewable energy access to an electricity grid. There are existing policies to learn from in China related to solar power generation, wind power biomass power electricity generation. Also China’s BNG industry is still in its infancy and lacks technologies and equipment, suggesting roles for policy-driven technological innovation. If the BNG industry is currently not competitive, then the technological solutions are unlikely to come from the private sector.

It is suggested that “front end” (supply-side) subsidies and “back-end” (demand-side) subsidies are unbalanced, and there should be more focus on the demand-side now i.e. market-making policies. It is thought that the government should provide back-end subsidies based on BNG production that will enable the private sector to build and run de-risked projects. Subsidies should be sufficient to support investors’ long-term and stable economic benefits, thus attracting new investment and social capital to further develop the industry.
6. **Finland: business ecosystems related to biomass-based textiles and plastic substitutes**

Finland has for a long time expressed an interest in developing a technology-based bioeconomy due to having sustainable forestry that is looking for value-added applications. The aim of this study was to give understanding of innovation development pathways of two important new application areas in Finland that use forest-based biomass:

- cellulose-based textiles
- bio-products and biocomposites replacing plastics.

Special emphasis in the study was given to the renewal of existing companies and the formation of new companies enabled by these development pathways and innovations. Thus, interviews were conducted with multinational enterprises (MNEs), start-ups, research organisations, a PPP and a funding organisation from the point of view of commercialisation, as well as for policy perspectives.

6.1. **The ecosystem(s)**

The Finnish bioeconomy ecosystem for cellulose based products consists of the traditional large forest industry companies such as UPM, Stora Enso and Metsä Group and a number of innovative start-ups developing new bio-products and biocomposites like Paptic, Elastopoli, Woodio, Sulapac and Welmu International, and for cellulose-based textiles like Spinnova, Infinited Fiber Company, with very few mid-sized companies in between. Universities and research institutes have an important role in the commercial ecosystem, as many of them are focused not only on basic research but also applied research and commercialisation. In the development of cellulose-based textiles, Marimekko as the brand owner has been actively participating already in the development phase. However, overall, a group that is missing from the established innovation ecosystem is clients.

The Finland case study was useful in addressing how partners are selected. Typical criteria for selecting new partners for industrial ecosystem include market knowledge from the business field or market area or substance knowledge about technologies or materials. For some companies, key value for partner selection is to enable quick market entry. Criteria might also be sustainability commitments or strategies and quality standards. Others target big volumes: global brand owners with big sales potential but also companies with large production capacities to meet demand.

At an OECD workshop in Kraków, Poland, Tasa identified gaps in the ecosystem for Finland to be aware of (in red on Figure 2). Two of these, the lack of demonstration plants and technology and solution providers, are common to many OECD countries.
6.2. Main policy conclusions

The guiding focus should be that the phase of development in Finland for the cellulose based textiles and bio-products and bio-composites replacing plastics is at the end of the Development phase and at the beginning of the Take-off phase. Policy needs to reflect that critical inflection point, and the messages below all relate to this.

The case study identified a range of policy issues. Regarding business models, tradition (i.e. large volumes of bulk to few clients) does not match new needs. Within the ecosystem, research organisations were closely involved, but medium-sized companies were clearly missing. There is a need to foster mid-size companies. However, in innovation policy this has been elusive in many different technology areas. Large companies buy innovative SMEs when they succeed, resulting in the sector consisting mainly of large and micro-companies, and mid-sized companies are often missing. Funding for demonstration-scale activities needs to be promoted to de-risk private investments.

Policy could encourage new and renewed business models. The traditional forest industry companies control the beginning of the value chain. However, their main income is from bulk production and selling these large volumes to few clients. Developing value-added products to a more fragmented market is still a smaller business sector. The challenge is that using side streams as raw materials might require adjustment or even special production lines additional to their normal processes. Thus many innovations are first commercialised through start-ups. This can create intellectual property rights (IPR) problems that slow down the innovation process.

Demonstrator plants, in common with other countries, are missing which is slowing down commercialisation. Financing for R&D is overall not sufficient for implementing mid-sized production facilities (between EUR 1-100 million). Subsequently investment decisions for demonstration infrastructure is crucially needed and it should be located close to the participating companies.
Enhanced networks and capacities to understand the entire value chain are needed. Networking is crucial to increase knowledge about new business areas and customer needs. The main knowledge gaps are related to the end of the value chain: lack of market knowledge of the new industry. Thus, networking within the extended value chain is critical and cooperation with brand owners is needed. The market knowledge can be increased if target market players are included as participants and partners already at the product development phase.

Promote at national and international level uptake of standards. New standards and EU regulations are needed to fit the new materials and products: industry standards should be renewed to base on functionality and not on materials used.
7. France: a private sector case study – Bazancourt-Pomacle

The most prominent example of an industrial ecosystem in rural France is the ARD integrated biorefinery. ARD is a mutualised private structure, owned by major players in the French agri-business as well as regional farming cooperatives. It was created in 1989 by exploiting the notion of value creation through non-food applications to find new opportunities from the produce of its shareholders (e.g. cereals, sugar beet, alfalfa, oilseeds). The site combines the activities of an industrial ecosystem, an industrial incubator and a territorial biorefinery. The site employs 1 100 people directly and another 800 indirectly.

7.1. The ecosystem

ARD started two subsidiaries – Soliance (molecules for cosmetic products) and BIODÉMO, the largest capacity demonstration platform in France, which has hosted Amyris, BioAmber and Global Bioenergies among others. Air Liquide joined the ecosystem in 2009, building a plant to capture CO2 for sale from bioprocessing activities at the site. In 2018 Givaudan, the world’s largest flavours and fragrances company, joined the ecosystem (Figure 3).

The innovation hub Biométhanol is an open hub in the field of biorefining. BRI brings together various biorefineries at Bazancourt-Pomacle, the R&D centre ARD, as well as the French engineering schools Ecole Centrale Paris, Agro Paris Tech and NEOMA Business School. Therefore, it covers the value chain from fundamental research to the pre-industrial prototype.

Cristal Union is a French cooperative sugar company. Cristanol operates the ethanol fermentation plant. ADM Chamtor transforms and processes wheat into starch-based products. Wheatoleo is a French company that develops innovative surfactants for the detergent, industrial, and plant protection markets. The Futurol project aims to put on the market a process, technologies and products (enzymes and yeasts) to ensure the production of second-generation bioethanol from dedicated whole plants as well as agricultural and forestry co-products, green residues and other biomass lignocellulose.

A crucial part of the ecosystem is the 10 000 farmers who supply the feedstocks (wheat and sugar beet). They have an alternative outlet for their produce that gives more certainty year-on-year, which allows them to make investment decisions on their farms. Given systemic problems with low prices for agricultural produce, this can be considered to be an element of sustainability.
Additionally there are several joint ventures (JVs) of high interest in the bio-based production world:

- Dupont Tate and Lyle for the production of 1,3-propanediol in the United States, further processed in polymer by Dupont on the same site
- Corbion-Total in Thailand to produce polylactic acid (PLA) based on lactic acid produced by Corbion’s plant on site
- BASF-Avantium for the production of Polyethylene furanoate (PEF) at a demonstration scale and further at industrial
- Global Bioenergies and Cristal Union for elaboration of business plan and a process optimisation stage prior to the construction of an isobutene production plant.

An important insight is how private companies select new members for their ecosystems. New industrial partners for ARD should amplify the circular economy by using co-products, spare energy or water for existing activities. If they bring a new activity it should not significantly have a negative impact to the environment, such as solid or liquid waste production, volatile organic carbon emissions, and generation of noise. For new business partners, they should ideally participate in the sustainability of the existing activities by bringing an opportunity of business risk diversification.

Another aspect of operations worthy of analysis as a circular bioeconomy ecosystem is on-site industrial ecology activities. This involves effectively recycling various resources so that the ‘waste’ of one process becomes a resource in another. On this site there are several of interest that speaks to efficiency gains: synergies of water, steam and energy, effluent, R&D, products and byproducts, even organisational and drilling synergies (Schieb and Philp, 2014).
7.2. Main policy conclusions

ARD selected the following as the main contributions that the public sector can make to improve building their industrial ecosystem. The overarching role should be to facilitate the development of the bioeconomy, through various actions:

- Generate real positive communication to the population about what the bioeconomy is, including the recognition of the biomass producer roles and their positive impact on environment and job creation.
- Consider that this is a transition period, and that financial risk sharing tools through public-private partnerships have to be emphasised.
- Encourage the formation of specialised staff to these new businesses, including technical, and commercial entities.

The biorefinery is located in a rural area close to Reims, and the company finds it easy to hire graduates and people from surrounding villages. However, the plants are running round the clock, seven days a week, on a 5-shift basis, and the company finds recruitment for these types of jobs difficult. For a bioeconomy to flourish there needs to be a robust education system at all levels.

The success of the operation is evidence that the distributed manufacturing model can work in the bioeconomy. This model is widely quoted in bioeconomy literature but it is a model quite opposite from the fossil economy model of centralisation and mass production at sites distant from the feedstocks. It is able to do this by product diversification to serve niche markets that do not require large volume of biomass, and a strong market; scientific and technology knowledge are differentiating strengths.

The company has several public sector interfaces, especially around its open innovation hub, including: CEBB (Centre Européen de Biotechnologie et de Bioéconomie) an academic research centre within the frame of a partnership between Region Grand Est, Departement de la Marne and Grand Reims. The company also helps fund a research chair from Ecole Centrale Supelec, Agro Paristech, Neoma Business School, and the University of Reims Champagne-Ardenne.
8. Italy: building the Novamont ecosystem

The case study from Italy is important as it has a larger focus from the private sector than other case studies, especially from Novamont, a leader in green chemistry and bio-based plastics. Another component of the Italy case study is inputs from the national cluster SPRING. The SPRING Cluster was founded in 2012 on the initiative of Biochemtex, Novamont, Versalis and Federchimica in response to the “Notice for the development and strengthening of national technological clusters” referred to in a Directorial Decree of the Ministry of Education, University and Research.

Italy was an early adopter of bioplastics, especially biodegradable bioplastics, and the company Novamont became interested in developing its own value chains. In this example there is much greater emphasis on the private sector. The production of Italian bioplastics already generates employment for around 3 200 positions. However, when the entire supply chain is considered, there are around 9 000 jobs directly or indirectly related to organic waste recycling, from collection to management. It has been estimated that employment related to the whole supply chain for the production and management of Italian bioplastics is around 12 000 positions, representing about 100 jobs for every 1 000 tons of bioplastic produced.

To remain a key player in biodegradable bioplastics in Italy, Novamont takes part in research, development and innovation projects in collaboration with Italian and international entities, aiming to create strategic partnerships among the research, industrial, agricultural and institutional fields and to generate new integrated supply chains.

8.1. The ecosystem(s)

The development model of Novamont is to created biorefineries integrated into a local area. The company focuses on the production of a range of bio-products (bioplastics and biochemicals) with high added value. Innovative agro-industrial value chains are developed, starting from local raw materials (low input crops, residues). This requires a respect for specific local conditions and the valorisation of abandoned and marginal land. Where possible, the reconversion of old and/or abandoned industrial sites through first-of-kind proprietary technologies is adopted. This creates new opportunities for the entire value chain and collaboration with the actors of the territory: farmers, researchers, industrial partners, local institutions, citizens and associations.

The case of agricultural mulch films is an example of how Novamont can interact with primary producers at the start of their ecosystem and develop bio-based products to address specific problems. In Europe about 85 000 tonnes per annum of mulch films for agriculture are used, covering 460 000 hectares. At the end of their lifetime, mulches are heavily contaminated and therefore difficult to recycle.

In the EU, the most common disposal route is still landfilling (about 50%), followed by incineration and finally mechanical recycling. At the end of a crop cycle mulches are heavily contaminated and therefore difficult to recycle.

Biodegradable mulch films were brought to the market in the 1990s. They proved comparable in field studies to conventional plastic mulches in terms of mechanisation, control of weed and crop quality and quantity. They are fully biodegradable in soil, meeting the new CEN standard on biodegradable mulch films (EN 17033). Moreover, they can be
used with good results on crops that are not normally mulched with plastic films, such as rice, maize and vine tomatoes.

Mater-Bi, a subsidiary of Novamont, have analysed biodegradable mulch films used for vegetable cultivation for alignment to the SDGs, and it was found that eight SDGs were applicable for mulch films. This serves to underline the role that these products may have on territory, on the environment and on society.

To show more generally the Novamont model, Figure 4 below can be considered to be the Novamont ecosystem.

![Figure 4. The Novamont ‘ecosystem’ in Italy.](image)

Source: Courtesy of Novamont, November 26/2018.

8.2. Main policy conclusions

The private sector in Italy, in particular Novamont and companies associated with their business, have been ahead of policy development for a long period. There are lessons that governments can learn from their experiences. Considering Italian bioeconomy and circular economy policy, it follows from the successful business model adopted by Novamont and associates.

The Italian bioeconomy strategy (Bioeconomy in Italy, 2017) aims to achieve a 20% increase of bioeconomy-related economic activities and job positions in Italy through improvements in sustainability production and quality of products in each sector and through the creation of new investments. To achieve the first goal, many perspectives have to be considered: exploitation of all the interconnections between primary production and transformation sectors; valorisation of marine and terrestrial biodiversity, circularity and ecosystem services; creation of new value chains, longer and routed, allowing the restoration of abandoned areas/plants and marginal lands. The strategy also includes action aimed at the promotion of bioeconomy in the Mediterranean area.

In order to facilitate the creation of new business, the main policy issues to consider are: increase in investments in R&D, spin-off, start-up, communication, education and training;
improvements in the coordination between stakeholders and policies on a European, national and regional level; promotion of specific actions for the development of a bioeconomy market, such as green public procurement. The strategy aims to produce new knowledge, technologies, services, but also to develop regulatory capacity, and public awareness.

Strategies for Smart Specialisation, provided by the Italian Conference of Regions and Autonomous Provinces, shows how the bio-based industry is second only to the agro-food sector. The potentials are related in large part both to the valorisation of wastes coming from food supply chains, with the aim of reducing environmental impacts, and to the development of dedicated crops in marginal agricultural areas, not in competition with food production.
9. Japan: biomass towns and biomass industrial cities

A cornerstone of biomass exploitation policy in Japan has been the Biomass Towns initiative and the follow-on Biomass Industrial Cities initiative. Others include The Fundamental Law for Promotion of Biomass Utilization of 2009 and the Biomass Commercialization Strategy of 2012. However, biomass policy predates these actions in Japan by several years.

9.1. The ecosystem(s)

The case study of Japan is quite a radical departure from the others. It has a strong focus on towns and industrial cities becoming entire bioeconomy ecosystems. Given the widespread nature of the biomass towns and cities, the case study is effectively national, but with plenty of scope for focus on individual towns and cities. One way to regard the impacts of these policy actions is that the distributed manufacturing model has taken on the geography of a whole nation.

In 2010 the cabinet decided upon the Basic Plan for Promotion of Biomass Utilization, which was followed up in 2016 with the New Basic Plan for Promotion of Biomass Utilization in 2016. In the new Basic Plan there is a focus on activities that generate more economic value. Goals are aligned for: industrial development and job creation; reduction of waste disposal costs and labour, and; the supply of cheaper energy and products. It plans for a modest expansion of the utilisation of biomass from 23 million tonnes per annum in 2010 to 26 million in 2025.

In the Biomass Towns concept, biomass materials are envisaged to be used by different constituencies of a town rather like the utilisation of waste materials in a waste exchange i.e. a ‘waste’ material from one constituent is a feedstock for another. In the context of biomass towns the ‘constituencies’ include factories, restaurants, households, farms and forests. They are augmented by biomass conversion facilities such as electricity and heating plants, ethanol plants and composting facilities. By 2011, 318 out of some 1,700 municipalities had developed their Biomass Town plans.

Some Biomass Towns succeeded in regional revitalisation through increase of employment and decrease in waste disposal costs. However, uptake of the plan was by no means complete, and several causes were identified, including a lack of: reference models of effective activities; an appropriate evaluation of achievement of activities and a technological system for efficient utilisation of biomass. With lessons learned, the Biomass Industrial City initiative was launched in 2013. Like the Biomass Towns initiative, the vision is to create industry utilising local biomass and building a local circular economy, and to stimulate rural development.

The government of Japan provides support, such as institutional/regulatory technique advice/consultation and best practices as well as introducing relevant measures (e.g. subsidies, tax benefits). As of 2017, 79 municipalities had been chosen to implement biomass industrial cities. The example of Shikaoi-cho as a Biomass Industrial City is given in Box 2.
Box 2. Shikaoi-cho as a Biomass Industrial City.

Shikaoi-cho in Hokkaido has regional characteristics of large-scale dairy farmland. Odour from domestic animal manure and environmental loads on groundwater and rivers have been target problems to solve. Part of the solution is a biogas plant and composting facilities. Electricity generated by biogas power generation is used in the facility and surplus electricity is sold to the electric power company by the feed-in tariff (FIT) system to ensure economic efficiency. The digested liquid is released to agricultural land as liquid fertilizer and surplus heat is supplied to agricultural greenhouses and a fish aquaculture (high value sturgeon) facility adjacent to the site of the biogas plant. As such, Shikaoi-cho works on various economic activities while utilising energy efficiently. In anticipation of the future hydrogen society, with budgetary assistance of the government, a demonstration project is under way to manufacture hydrogen from methane gas produced at the biogas plant for use as automobile fuel.


9.2. Main policy conclusions

Japan was an early adopter in biomass utilisation policy. The Biomass Nippon Strategy (2002) was Japan’s first national strategy to utilise biomass as a valuable resource. The decision to create Biomass Industrial Cities was taken with lessons learned from the Biomass Towns.

Particularly in the utilisation of unused biomass such as such as forest residues and waste-derived biomass such as livestock manure, it can be seen that local stakeholders (including forest owners, forestry associations, farmers, regional agricultural cooperatives, plant manufacturers and operating companies) have started to work collaboratively i.e. collective action has started to build value chains.

One of the major premises for project implementation was consensus building by conducting briefing sessions at a local level. In activities like burning biomass for electricity or heat generation and treating wastes for methane fermentation, it was considered essential to understand local residents and to gain their trust. In the Biomass Industrial City/Region schemes, municipalities are positioned as the main formulators of the plan. They then coordinate with local farmers, plant manufacturers, local residents and other relevant stakeholders in the planning process in a voluntary manner.

From this very local scale, it is desired that using resources such as microalgae and some unutilised biomass could bring about significant economic impact and could lead to strengthening the competitiveness of global enterprises. This strategy resonates with the distributed manufacturing model, and it is significant that the process starts locally.

The dynamics of agriculture in Japan have changed radically in the past few decades. Much fewer people work in agriculture now and part of the biomass policy effort is to address the issue of abandoned farmland. For example, demonstration tests are being conducted to cultivate resource crops such as Erianthus on abandoned farmland and to pelletise it for fuel use.

If the Erianthus demonstration test goes well, it will become possible to make economic activities by effectively using larger scale abandoned farmland. At the same time,
maintaining agricultural land as farmland makes it possible to plant food crops in case of emergency, which is expected to enable supply and demand adjustment of land use. In other words, biomass policy also has a major goal of revitalising agriculture and rural life. Such an agricultural land use model is considered to have the potential to contribute to food security in Japan and in other countries.

The market size of the biomass industry has expanded mainly due to power generation efforts taking advantage of the feed-in tariff (FIT) system for renewable energy that came into force in 2012. However, there are constraints upon the electricity network capacity that need to be urgently dealt with at national level if biomass utilisation is to continue to expand. In addition, attention has to be paid to securing economic feasibility after the end of the FIT purchase period. This must be carefully considered at local business level as well as nationally.

Consistently in planning in Japan can be seen a modification of the term “think locally, act globally”, an idea important in town planning. Rather, the theme consistent with the Japan case study more closely resembles “act locally to prepare to act globally”.

10. Norway: value chains based on carbon waste gases and marine residuals

The two bioeconomy value chains analysed in the Norway cases are based on biotechnology as the main enabler, supporting Norway’s large marine sector. In the first case, carbon waste gases are utilised for the production of fish feed by microbial fermentation and in the other, enzymes are used to valorise marine residuals, e.g. off-cuts from fillet production. The two ecosystems can be represented graphically in Figure 5 and Figure 6, respectively.

10.1. The ecosystem(s)

10.1.1. Waste gas fermentation

Norway has some significant point sources of waste gases from e.g. production of fertilizers, metals and from the oil and gas sector. In recent years research into fermentation of carbon gases such as CO and CO₂ with H₂ as energy source, has become industrialised. This represents an opportunity to valorise these gases while augmenting the sugar value chain. Using these waste gases in bioeconomy applications also relieves pressure on land and avoids issues of indirect land use change (ILUC).

For most nations deciding to develop these new bioeconomy value chains, there is almost always one or more gaps or weaknesses in the chain. In small countries there is in fact often more than one. In order to utilise specific opportunities, there has been a need to strengthen business ecosystems with key technology elements. Within the case 1 ecosystem depicted in Figure 5, Norway possess technological skill and strengths in CO₂ concentration/purification and in ‘green’ hydrogen production by electrolysis of water, while important complementary gas fermentation technologies are missing, including know-how on the specific microorganisms employed. Analysis of the gaps and weaknesses in the value chain identified the need for three main families of policy instruments:

1. techno-economic workshops to clarify feedstock opportunities
2. policies to attract foreign technology providers
3. policies to trigger private investments in new manufacturing.

Figure 5. Case 1: The carbon gas fermentation business ecosystem.

Gas fermentation can generate a number of different products, ranging from protein ingredients to bioplastics and jet fuel. Exploration of these potentially new value chains has been stimulated by government facilitators such as Innovation Norway, organizing cross-
sectorial workshops bringing together industries which normally has very little interaction, such as power companies, metallurgical industry and manufactures of fish feed or plastics. The lack of certain key technologies was recognised as a specific barrier in the value chains described above. A policy action to address this is to provide demonstration scale facilities. Demonstration is often seen as an essential stage in technology development, but one that is high-risk and unattractive to the private sector. Using public money to build multi-user demonstrator facilities is usually seen as a trigger for private investments, as it demonstrates government commitment to de-risking.

The Norwegian Centre for Bioprocessing & Fermentation (NBioC) is a public-private partnership project under development in Stavanger on the Norwegian west coast. It will comprise an open access scale-up and pilot facility for conventional, as well as gas-based fermentation; a commercial manufacturer of industrial enzymes, and; hosting the demonstrator plants for two international technology providers in gas fermentation.

10.1.2. Enzymatic refining of marine residuals

Another priority in Norway is to make better use of the raw materials from fisheries and fish farming, for instance by adding value to fish heads, off-cuts and other waste materials from fillet production. Such side streams for instance from salmon processing (comprising about 50% of total fish weight), is traditionally used for relatively low-value products e.g. fishmeal, but there is potential to generate significantly more value through advanced biotechnology-based processing methods. The core of such methods is enzymes tailored to the type of fish and its specific protein and lipid components.

As for the gas fermentation case, the entire value chain needs to be developed. While Norway has been a pioneer country for enzymatic processing of fish residuals, there is a lack of domestic industrial skills in enzyme development and manufacturing. This weakens the ability to further improve products by using more sophisticated enzymes, thereby reaching out to high-end markets such as ingredients for food and cosmetics or even pharmaceuticals. Thus, recruiting enzyme expertise would be an important stepping-stone to new market opportunities.

As with the previous example, a need for demonstration scale enzymatic refining has proven important for industrialisation by de-risking private investments. Biotep is a national facility for scale-up of marine biorefining located at Kaldfjorden, close to Tromsø in the north of the country. It is an open access pilot facility for processing of marine co-products inaugurated in 2013. It has state-of-art equipment for scale-up, optimisation and test production, including a full process line for enzymatic hydrolysis.

Norway has several marine clusters and industrial ecosystems. Interestingly, a national innovation network, Norwegian Industrial Biotech Network, were instrumental in transferring these methods to the agro-sector, and a new 30 000 ton/y factory for enzymatic processing of chicken off-cuts has recently been opened (Figure 6).
In both cases a policy matrix approach was taken to identifying the policy needs to develop the value chain, and thus the ecosystem of actors. The generic approach is applicable between different value chains, different regions and different countries. That is, it is scalable. In summary, the strategy can be described in five points:

1. create synergies by taking a value chain perspective in grant programmes and policy development
2. stimulate international technology partnerships and cross-sectoral knowledge transfer (e.g. in the above enzyme example, the transfer from marine to agri-food)
3. offer scale-up facilities to reduce private investment risk and attract technology providers
4. grants for techno-economic assessment and LCA studies
5. use regulatory measures to increase the competitiveness of sustainable products.

10.2. Main policy conclusions

New products in the advanced bioeconomy are often faced with immature markets and competition from cheaper, but less sustainable alternatives. One of the most important public incentive for stimulating growth in the bio-based industries is predictable, long-term policies that give the industries predictability for their investments into projects which often have a longer payback time. These policies, as well as the underlying national and societal ambitions, should be communicated clearly to the industry.

Public involvement in establishing industrial networks/clusters and other measures, e.g. cross sectoral workshops, to stimulate new interactions between companies, has been identified as another important catalyst for innovation in bio-based value chains.
There is a need for public co-financing of research and innovation throughout the technology readiness level (TRL) scale. Both industry cases outlined above recommend a particular focus on the mid-to-high TRL-levels, as this phase is essential for significant reduction of technology risk and subsequent commercialisation. One step is public support for multi-user process scale-up and pilot production facilities (TRL 5-6). The next, and more challenging is policies helping new technologies mature beyond the demonstration phase (TRL 7-8), which is generally seen as key to attracting private investments.

While policies and instruments should aspire to be as generic as possible to avoid favouring specific industries or technologies, some major societal challenges or market failures may require tailored measures to be effective towards a desired goal.

In summary, the case studies suggest the following general policy instruments would be relevant for stimulating the circular bioeconomy and its business ecosystems (not in any order of priority):

- long-term public strategies on industry regulations and open communication
- raising awareness by facilitation of knowledge dissemination and networking
- public funding for early stage research and competence building
- policies and incentives for product labelling and consumer information
- public funding and support targeting mid-to-high TRL-levels (scale-up and demonstration)
- public incentives for industry collaboration and a holistic approach to new value chains.
11. Sweden: a focus on biorefining for fuel production

In Sweden, largely driven by climate policy and a desire to reduce dependence on fossil resources, significant efforts have gone into commercialising biorefineries. To date these efforts have had limited commercial success: of four major demonstration plants that have been built, only one is still operating. In addition to publicly funded demonstration plants, which largely have failed, there are four successful and commercially operating biorefineries. Two of these use forest for feedstocks, the other two were built to use agrarian resources such as rapeseed oil for biodiesel production and wheat for ethanol production.

11.1. The ecosystem(s)

In the two cases of forest-based biorefineries, Domsjöfabriker is a sulphite-based speciality pulp mill that has been developed into a biorefinery producing a multitude of different products from forest-based resources. Among their main products is a specialty cellulose for the textile industry as well as lignin, bioethanol, biogas, hartz (resin) and CO₂. Due to its unique character and lack of similar sulphite-based mills, the concept is not scalable beyond existing sulphite-based mills.

The second case has had a long, but promising development that also has resulted in a vibrant ecosystem of actors, distributed all over Sweden. The development of the ecosystem started in 2008, with a joint venture between Preem, the small engineering company Kiram and the forest industries Södra and Sveaskog. The purpose of the joint venture was to build a facility in the north of Sweden, using crude tall oil for producing biodiesel. As Preem joined the project, the concept changed from the production of regular biodiesel from tall oil to a less complex intermediate that could be used to make a hydrogenated vegetable oil (HVO) that is 100% blendable with conventional diesel.

The idea of a distributed production, creating an intermediate product at one site, and transporting that to a different site simplified the production at Sunpine significantly. Moreover, it lowered the overall cost of the project since the existing infrastructure at Preem could be used in combination with expertise in making fuels that can meet existing standards and blending requirements. The concept of distributed production was also going against the basic idea behind the main investments being undertaken in Sweden for developing forest-based biorefineries at the time, which focused on producing a ready-made fuel at the same site where the biomass was refined.

After successfully developing the process for producing renewable diesel, development work could start to further improve the yield of valuable products. Sunpine started to develop processes for extraction of rosin chemicals from the crude tall oil in collaboration with a Japanese pine chemicals company, Harima Chemicals, and its daughter company Lawter. Sunpine then also started to extract turpentine. Both projects had a strong and positive impact on Sunpine’s financial results, and increased the overall yield from 60% to over 70%.

Crude tall oil is, however, a very limited commodity raw material compared with fossil oil and it will not be possible to increase the production much more. As a result, several firms have started to look for and develop other resources. Following in the footsteps of Sunpine, the goal of these firms is to scale up the concept of “distributed biorefining” in which the infrastructure at oil refineries is taken advantage of in combination with the existing...
infrastructure at sawmills, pulp and paper mills and in district heating (see Figure 6 for examples of ongoing demonstrations). A significant part of the development work is carried out by actors with informal ties to Preem, but where Preem’s capacity to upgrade bio-based oils plays a core role for reducing the complexity of the different projects and meeting existing fuel standards.

Figure 6. Examples of significant initiatives that could deliver towards Preem’s and national targets through a “distributed” biorefinery concept

Suncarbon and Renfuel are examples of small technology-based start-ups with promising new biorefinery projects. In collaboration with research institutes, universities as well as partners from the forest industry, the two competing firms develop a process based on lignin separation and catalytic treatment. The intermediate product is a bio-based oil that can be blended into the refinery process. The added benefit of the process is that through a smaller investment in lignin separation, the pulp and paper mills can off-load the recovery boiler and thereby avoid expensive new investments when production capacity is increased at the mill. Implementing the technology at a large scale, possibly 2 million tons of lignin oil in Sweden could be produced. Another example is SETRA, a major owner of sawmills in Northern Europe. SETRA have entered a technology cooperation with a European technology supplier for developing an intermediate bio-based oil, which can be blended into the refinery process, from sawdust. Large incumbent firms such as Valmet/Fortum and SCA as well as a Norwegian joint-venture, Biozin, have also entered the field and have demonstrated concepts where the goal is to produce an oil which can be upgraded within a refinery infrastructure.

Hence, the prospect of supplying various type of forest-based bio-based oils that can be upgraded in a refinery infrastructure is well under way and may pave the way to significantly reduced emissions from the transport sector. However, in analogy with Sunpine’s experience, the current investments also create opportunities for further investments in other products that can be extracted from the bio-based oil. Such products have the potential of improving the profitability of future distributed biorefineries in the long run.
11.2. Main policy conclusions

For making the above-mentioned business cases, policy has played a decisive role. It has been considered important that, firstly, the biofuels they would develop were not directly exposed to a fluctuating oil price, secondly, that they would be promoted in relation to their CO₂-reduction potential and, thirdly, that the fuels would be considered legitimate in the eyes of the public.

The initial investment in Sunpine could be made under less than ideal policy circumstances, since tall oil was easily accessible and the project had a fast payback time. However, for realising the other projects the political framework had to be redesigned. The main barrier for investing in forest-based biorefineries has been the temporary exemption from CO₂ taxes, which have been in place since 1991. The temporary exemption needed official approval by the EU at least every second year and has not created the necessary incentives for realising forest-based alternatives for transport fuels, mainly because investment security was not created for more than two years at a time, while the payback time for the necessary investments are in the range of 10-15 years.

The Swedish Biomass Association (SVEBIO), Preem and others started various initiatives for identifying and suggesting an alternative to the temporary tax exemption. With slight variations, the industry promoted, a so called ‘reduction quota’ to replace the tax break. In 2016, the Swedish Energy Agency, was also assigned by the government to investigate and propose an alternative to the existing tax exemption. The Energy Agency also concluded that a reduction quota, benefiting the biofuels that can provide the highest reduction of GHG emissions at the lowest cost, should be implemented. In 2017, the Swedish Government announced that the reduction quota would come into effect by July 01, 2018. Emission reduction levels have been specified for the years 2018-2020 and an indicative reduction has been set to 40% by 2030.

With the new incentive structure in place, Preem has estimated that they will increase biofuel production from 200 000 m³ to 3 million m³ by 2030. It has also spurred significant entrepreneurial activities in the field that potentially could deliver towards the new goal of Preem and Sweden’s ambitions to significantly reduce the domestic emissions from the transport sector.
12. The United States: building a biotechnology-based bioeconomy

The case study from the United States is the one most driven by biotechnology and other new technologies. Advances in genetic engineering approaches and DNA sequencing technologies over four and a half decades have accelerated innovation significantly in the United States. Concurrently, strides have been made in computing and data sciences, and the recent emergence of machine learning and artificial intelligence capabilities have increased the potential of engineering biology. When this is allied to drivers such as: plentiful availability of biomass; gaseous carbon waste feedstocks on the horizon, and; a very advanced system for procurement of bio-based products, then the choice of an ‘advanced’ bioeconomy built on engineering biology is a clear choice of direction for the United States. This was made clear in the 2012 US National Bioeconomy Blueprint.

The United States has chosen to base its ecosystem case study around the Agile BioFoundry. The US Department of Energy established the Agile BioFoundry to unite the capabilities of eight National Laboratories to integrate sophisticated synthetic biology tools including software for biological design, machine learning, high-throughput analytics, techno-economic and life cycle analyses, and expertise, into a platform for biomanufacturing of microbes for production of bio-based fuels and chemicals. It is aimed to develop biological approaches for production of advanced (non-ethanol) biofuels, renewable chemicals, and materials that represent low greenhouse gas alternatives to products currently derived from petroleum.

12.1. The ecosystem

Companies that participated in early discussions ranged from very small start-ups to mid-size and large biotechnology companies. A universal theme was an emphasis a need to accelerate the analytical aspects of the Design-Build-Test-Learn cycle. Work with private sector companies spans a variety of feedstocks, including algae, lignocellulosic crops, and single-carbon feedstocks. Apart from biotechnology companies of all sizes, then, the Agile BioFoundry appeals to a much wider cross-section of the bioeconomy, such as farmers, foresters, waste management companies.

Long-range transportation of non-liquid feedstocks presents a challenge to biomanufacturing, and an approach that enables distributed manufacturing near sources of biomass would not only address this barrier but also promises to create high-value jobs in more rural areas. Hurdling these shared barriers promises significant benefit to a wide variety of industry players as well as significant public benefit.

Among the first collaborating companies of the Agile BioFoundry were LanzaTech, Agilent Technologies, Lygos, Visolis, Kiverdi, and Teselagen. Department of Energy funding instruments have been developed to continue the expansion of the ecosystem.

- LanzaTech and Kiverdi have research portfolios that include the use of C1 waste gas feedstocks for the production of valuable products. LanzaTech is developing machine- and deep learning models to optimise continuous fermentation of industrial and synthetic gas using output from LanzaTech’s third generation genome-scale model of Clostridium autoethanogenum. A primary aim is the creation of an in-line artificial intelligence-guided process to monitor and adjust industrial fermentation conditions in real time, optimising the fermentation output.
• Agilent Technologies provides scientific instruments and has research foci including chemical analysis, life sciences, and diagnostics.

• Lygos uses biology and sugar to produce valuable bio-products at low costs. The company is developing an improved industrial host, *Pichia kudriavzevii*, an acid-tolerant yeast, to produce organic acids, chemicals that are generally expensive to manufacture petrochemically but that are inexpensive to biomanufacture.

• Visolis uses a hybrid biological and chemical processing approach to provide sustainable, carbon negative materials. The company is creating a new host organism that is acid-tolerant and capable of utilising cheap feedstocks, such as waste gas, to produce a hydroxyacid intermediate at demonstration scale. This can be subsequently upgraded to various valuable compounds using chemical processes for the polymer and plastics industry.

• Teselagen offers an artificial intelligence platform to accelerate the design of high-value chemicals, therapeutics and agricultural products. With the Agile BioFoundry the company aims to enhance tools to facilitate biomanufacturing design such as BOOST (Build-Optimization Software Tool) and BLiSS (Black List Sequence Screening). The company also needs a tool to enable efficient data collection EDD (Experimental Data Depot) to improve aspects of the Design-Build-Test-Learn biomanufacturing cycle.

This list alone attests to the very strong focus on new technologies and biotechnologies in the Agile BioFoundry ecosystem. Given the range of products and sectors served, it also shows that the foundry is in its truest sense a technology platform.

The Department of Energy enabled these collaborations and ecosystem building through a novel mechanism, the Directed Funding Opportunity (DFO), where the Department of Energy provided funding for the Agile BioFoundry to be used for an industry competition. Companies proposed a number of possible projects to be executed at the Agile BioFoundry with those government funds. Through this PPP it is expected that the Agile BioFoundry will also develop new tools and technologies and expertise to extend the ecosystem in the future.

Additional mechanisms for industry collaboration with the Agile BioFoundry are Collaborative Research and Development Agreements (CRADAs) and Strategic Partnership Programs (SPPs). CRADAs often involve larger scope collaborations including integrated process steps across subsets of the eight national labs and offer industry partners the opportunity to embed their researchers at the Agile BioFoundry. In most cases, industrial partners are expected to pay full-cost recovery for all Agile BioFoundry National Lab work performed under the scope of the project’s work. Under SPPs, collaborations tend to be smaller engagements and where the Agile BioFoundry performs a specific task for the industry partner. Academic collaborations are also ongoing at the Agile BioFoundry, with a main criterion for partnership being project alignment with the mission and vision of the Agile BioFoundry.
12.2. Main policy conclusions

12.2.1. A balance of fundamental and applied research investments by governments is important

In the United States as in other countries, the balance of government investments in fundamental, use-inspired, and applied research is not strictly defined and can change over time. When industry sectors can come together to identify high-risk, capital-intensive fundamental research questions that align with government priorities, high-impact partnerships can result and major barriers preventing bioeconomy advances can be overcome.

12.2.2. Public private partnerships are powerful and can serve a broad range of stakeholders

Investment

At many levels – local, regional, federal – government has the power to convene stakeholders to collaborate on and invest in shared priorities to effect great impact. The early ecosystem of the Agile BioFoundry shows that a broad range of industry stakeholders can be brought together to identify pre-competitive research challenges that, if successfully addressed, can benefit many sectors. This case study has shown that with continued industry interest, mechanisms of government investment can evolve toward those that involve cost sharing among companies, further maximising government returns on investment.

Regulatory engagement

Future products of biotechnology span a tremendous variety of sectors, from biofuels to renewable chemicals to non-livestock food protein sources to complex microbial assemblages for agricultural, mining, and nutritional purposes and more. Early engagement by regulatory agencies of companies with aspirations to bring such products to market better prepares these agencies for products that might require new regulatory pathways. Meanwhile, product developers are provided with early notions of what regulatory steps might be ahead. Engagement that expands beyond regulators and developers and includes non-governmental technical experts and members of the public can strengthen governmental regulatory processes, decrease regulatory delays, and increase transparency and trust.

12.2.3. Multiple investment mechanisms provide flexibility in rapidly changing landscapes and fuel a variety of public private partnerships

As industry needs continue to evolve and the value of Agile BioFoundry to industry has emerged, the Department of Energy is now exercising a number of funding mechanisms to broaden industry participation and incentivise co-investment, including Directed Funding Opportunities, Cooperative Research and Development Agreements, and Strategic Partnership Programs, in addition to cost-sharing requirements for applications for government funding opportunities.
12.2.4. Procurement policies provide certainty and create new markets

Government procurement strategies can be important policy tools for driving bioeconomies. For example, in January 2017, the US Office of Federal Procurement Policy (OFPP) reported that significant progress had been made in establishing a framework for the procurement of sustainable products. In their required fiscal year 2016 strategic sustainability performance plans, 21 federal agencies committed to more than 84,000 sustainability contracts worth more than USD 453 million in bio-based products to be delivered in fiscal year 2017. USDA analysis demonstrated how the US bio-based products industry generated American jobs (4.2 million in 2014) and substantial economic activity. The bio-based products industry contributed a total of USD 393 billion in value-added to the US economy. The industry has generated USD 127 billion in direct value with spillovers totalling USD 266 billion.

12.2.5. In summary

Strategic research investments, innovative and flexible funding mechanisms, public-private partnerships, regulatory clarity, and sustainability/bio-based procurement requirements are important policy approaches that can have significant positive impacts on bioeconomies, as described in this US case study.
13. Analysis of cases

Given that the case studies report diverging situations, from the very specific and local to region-wide (e.g. Canada) to country-wide (e.g. Japan), then finding unifying policy themes is a difficult task. Innovation ecologies are situation-specific; therefore, it would be erroneous to think that a broad innovation strategy can be easily transferable from one location or country to another (European Commission, 2015).

13.1. A systemic approach to value chain and ecosystem policy analysis

Many new value chains in the emerging bioeconomy suffer from what may be described as a “systemic challenge”. The key problem in such cases is that no part of the value chain is viable on its own accord, but depends on the success of the other parts in a systemic manner.

Typically, this is seen when combining a novel, poorly characterised feedstock with a relatively immature conversion technology, in order to meet an unestablished customer need. The chain is only as strong as its weakest link. High complexity and interdependency may create a perceived insurmountable barrier to progress. The only possible way forward might be public-private concerted action, involving coordinated innovation efforts and supportive policies throughout the whole chain. In a generalised way, one can express the systemic challenge as “negative synergy created when market risk is combined with feedstock risk, technology risk, as well as regulatory or political risk”.

Another version of the same problem is when the profitability of a new value chain depends on the complete future mix of end products; that is, the initially weak market forces are unable to create the required pull on the feedstock supply chain. It is only when all the players have successfully reached the far side of the ‘valley of death’ that the value creation will be sufficient to drive the system. Hence, if there is no individual actor with capabilities to develop the whole product portfolio singlehandedly, the investors will have to consider a systemic risk beyond the control of their own investment.

Box 3. A systemic approach: a case from Norway

Norway has encountered several examples of such systemic barriers, for instance related to exploitation of seaweed, new integrated biorefining of wood and the gas fermentation example given in the main text.

A particularly important example is the proposed catching of mesopelagic fish. According to recent scientific publications (e.g. Irigoien et al., 2014), this resource has been upgraded by a factor of 10, suggesting a global standing stock of more than 10 billion metric tons, i.e. 100 times more than the total current fisheries. If correct, this would provide a hugely important resource for human nutrition. The Nordic countries are contemplating a joint initiative to explore this resource, but are confronted with the need for concerted action spanning from marine research to market development. One needs to understand the marine ecosystems, the hotspots and seasonal variation. The biological research as well as the development of more efficient fishing gear and avoidance of bycatch, will depend on innovation in improved detection systems at greater depths. Researching the chemical composition of the organisms in question will determine the optimal processing
technologies and product opportunities. Regulatory aspects and policies will influence resource management, as well as product approvals.

Here we see the systemic challenge at play. The fishing companies will not undertake expensive trial fisheries without confidence in future commercial licenses; suppliers of enabling equipment will not invest in innovation without customers and; tailor-made processing technologies are not developed in the absence of an established market pull.

The two Norwegian ecosystem cases are further examples of systemic risk. The generic matrix below is referring to one of these value chains; the production of fish feed or biofuel by fermentation of carbon waste gases. It illustrates how different policy measures, supply side as well as demand side policies, can work synergistically, both at the specific and at a more generic level.

### Table 2: Generic Framework of Bioeconomy Innovation Policy

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Technology</th>
<th>Production</th>
<th>Market</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convert waste gases into value</td>
<td>Build novel tech platform</td>
<td>Trigger private investments</td>
<td>Sustainable fish feed and biofuel</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Objective</th>
<th>Specific</th>
<th>General</th>
</tr>
</thead>
<tbody>
<tr>
<td>Techno-economic feasibility studies</td>
<td>Targeted inward investments</td>
<td>Gas-fermentation scale-up plant</td>
</tr>
<tr>
<td>Discourage soy or palm oil</td>
<td>Regulations and policies</td>
<td>Collaboration and partnerships</td>
</tr>
<tr>
<td>Public facilities for scale-up</td>
<td>R&amp;D grants and product policies</td>
<td></td>
</tr>
</tbody>
</table>

Source: adapted from presentation and personal communication from Ole Jørgen Marvik, Innovation Norway.

### 13.2. The balance of supply- and demand-side measures

As a general observation, the case studies illustrate greater attention to supply-side measures than to demand-side (market-making). Evidence from the OECD has suggested that a greater balance is required (OECD, 2011). A conclusion from this study was:

“This interest in demand-side innovation policy has emerged as part of a greater awareness of the importance of feedback linkages between supply and demand in the innovation process. Demand-side innovation policies are part of an evolution from a linear model of innovation, usually focused on R&D, to a more broad-based approach that considers the full scope of the innovation cycle. 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.”

This strongly agrees with the “systemic challenge” outlined in Box 3.

Table 2 refers to a generalised framework of bioeconomy innovation policy (OECD, 2018b). It has been modified here: text in italics shows the policy families most often used in the case studies. There is seemingly a preponderance to supply-side policies and it is possible to speculate why the demand-side is relatively under-represented.
Table 2. Policy inputs for a bioeconomy framework.

<table>
<thead>
<tr>
<th>Feedstock/technology push</th>
<th>Market pull</th>
<th>Cross-cutting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local access to feedstocks</td>
<td>Targets and quotas</td>
<td>Standards and norms</td>
</tr>
<tr>
<td>International access to feedstocks</td>
<td>Mandates and bans</td>
<td>Certification</td>
</tr>
<tr>
<td>R&amp;D subsidy</td>
<td>Public procurement</td>
<td>Skills and education</td>
</tr>
<tr>
<td>Pilot and demonstrator support</td>
<td>Labels and raising awareness</td>
<td>Regional clusters</td>
</tr>
<tr>
<td>Flagship financial support</td>
<td>Direct financial support for bio-based products</td>
<td>Public acceptance</td>
</tr>
<tr>
<td>Tax incentives for industrial R&amp;D</td>
<td>Tax incentives for bio-based products</td>
<td>Metrics, definitions, terminology</td>
</tr>
<tr>
<td>Improved investment conditions</td>
<td>Incentives related to GHG emissions (e.g. ETS)</td>
<td></td>
</tr>
<tr>
<td>Technology clusters</td>
<td>Taxes on fossil carbon</td>
<td></td>
</tr>
<tr>
<td>Governance and regulation</td>
<td>Removing fossil fuel subsidies</td>
<td></td>
</tr>
</tbody>
</table>

Note: Italics refer to policy options cited more frequently in the case studies.
Source: Adapted from OECD (2018b).

This lack of attention to supply markets possibly reflects reluctance by governments to be seen to be intervening in markets and potentially contravening anti-competitive practices (Institute of Risk Management and Competition and Markets Authority, 2014). There may be a perception of a grey border between effective collaboration to promote whole system innovation and change and the motivation of self-interest, thereby creating (perceived) conflict of interest in public service. The coordinated stimulation of specific assets such as one particular feedstock or a specific value chain, could easily be perceived as ‘politicians picking winners’.

It is worth elaborating on public procurement as a market-making policy because it accounts for some 13% of GDP on average in OECD member countries (OECD, 2012). Public procurement for bio-based has proven difficult to implement for various reasons. A common reason is that public procurers are usually tasked with finding the cheapest products, and bio-based often are not at a mature enough stage to compete, especially with energy and fossil-derived fuels and petrochemicals.

Fossil carbon is generally cheaper in production with no uncertainty associated with seasonality, crop failure and stability plus cheaper processing with less oxygen content and fully depreciated refineries and transportation infrastructure. For a very new industry such as bio-based these factors make it very difficult to compete.

While possibilities exist to use public procurement for facilitating market entry for innovative bioeconomy products, challenges exist on both sides of the market. On the supply side, only a small proportion of all bioeconomy products concern the business-to-consumer (B2C) market in which public procurers normally operate (e.g. fuel and consumer products). The largest share of bio-based products is chemicals and intermediates, which are only interesting to private industry in a business-to-business (B2B) market.

On the demand side, public procurement is a fragmented institutional landscape: in the EU at the central governmental level only, more than 2 100 procuring authorities are listed. This fragmentation inhibits coordination, and industry-specific knowledge and capacity building.

Various governmental schemes address this issue. There are very few that are specific to bio-based products, but the most advanced is the USDA BioPreferred Program³, which has evolved into a wide-spread and sophisticated system in the United States, with a voluntary
13.2.1. Carbon tax as a demand-side measure

Often ignored in bioeconomy policy documents and discussions, carbon tax in accordance with the polluter pays principle may in fact be a very effective way to promote a circular bioeconomy as an instrument not targeting the bioeconomy. However, greater scope for use of carbon tax can lie in its use as a generic demand-side incentive alongside a specific bioeconomy supply-side incentive.

13.3. Policy alignment

13.3.1. Alignment with industry policy

Alignment of the bioeconomy with the circular economy and industrial policy is a common theme in many countries (beyond the case studies). However, this has to go beyond discussion and documentation into formal policy. As concepts, the bioeconomy and the circular economy are often intertwined, and are increasingly presented as such in guiding documents. But the coherent combination of the two concepts is still challenging because of their differences in historical development and in principles.

Historically, initiatives for the circular economy often originate in the recycling and environmental sector, and in the related R&D. The development focus starts from large quantities of under-utilised inorganic waste streams, such as metals, plastics, or industrial mineral side streams. New circular initiatives increase the higher added value to be derived from these resources, through industrial symbiosis or novel upcycling technologies. So the circular initiatives grow in connection with industrial clusters and regional ecosystems, and are as such much easier aligned with existing industrial policy.

Initiatives for bio-based production are more often created from technological innovations in research organisations. The steps towards industrial application requires then the development of new clusters, business partners and value chains, rather than the integration in existing clusters as for initiatives for the circular use of inorganic resources. For instance, in the case of Sweden it was stated that bioeconomy in Sweden is still a research strategy. The alignment of bioeconomy policy and industrial policy may often be a larger challenge.

13.3.2. Bioeconomy, circular economy and the cascading use concept need to be aligned

The alignment of the circular economy policy with bioeconomy policy requires coherence between the principles of downgrading and cascading. In many cases complete valorisation of feedstocks requires a cascading of biomass through higher value-added products to eventual energy generation with residues after bio-based production. While this is attractive conceptually, there is very little policy to support cascading use of biomass.

The recycling chains for organic side streams are seasonal and perishable, which lead to structural differences with inorganic waste streams. Large scale selective collection of organic side streams is challenging, because specific bio-based sources quickly lose valuable compounds, and have to be treated immediately. This prohibits the development of large-scale and long collection chains that would enable industrial scale applications. This problem can be overcome in two instances. First it is possible to develop larger ecosystems based on organic materials that are less perishable (such as wood-based
materials), and where local conditions allow the integration of the entire value chain in one place. An alternative solution is to provide decentralised pre-treatment installations at the producers of the organic side streams, in order to reduce the perishability by filtering, drying or separation techniques. The resulting biomaterials can then be integrated in larger value chains.

This entire development has to ensure that the overall benefits remain positive. This implies that cascading will not always be appropriate and perhaps this is why it is not more frequently deployed into policy instruments. The update to the European Commission Bioeconomy Strategy (European Commission, 2018) recognises the need for not overusing the cascading principle. Higher added value is not always the solution. It is really important not to incentivise cascading use of carbon if the energy cost is higher than the gain:

“While the conversion pathways towards added value products may exist, especially using homogenous by-products and waste coming from agriculture, forestry-based, marine and agri-food industry sectors, ensuring their profitability requires both a techno-economic analysis and that trade-offs are minimised, such as minimising environmental impacts and externalities due to logistics.”

Indeed, it is important to mention that the limitations of the cascading principle should always be determined as a compromise between energy, bioeconomy and circular policies.

The idea of a techno-economic analysis was one broached in the Norway case study. Such an analysis would seem essential when funding policy is directed by technology readiness level, TRL. However, these analyses are expensive and may be beyond the reach of many small companies. Hence there may be a case for public subsidy if a promising technology may fail to emerge due to the inability to finance a techno-economic analysis.

To illustrate how the cascading principle and industrial ecology can work in practice, a very good example is the ecosystem around the pulp and paper mill at Äänekoski, Finland (Box 4). In this example, the products are traditional (e.g. pulp, paper, tall oil, turpentine), along with novel, higher value products and eventually energy to run the mill.

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**Box 4. The Äänekoski ecosystem demonstrates the cascading principle.**

Over a period of decades, a local business and industrial ecosystem has evolved around a Metsä Group pulp mill operated in Äänekoski. Examples are chemical plants of CP Kelco and Minerals Nordic, and a cheese factory of Valio. CP Kelco processes pulp to carboxymethyl cellulose, a thickener in ice cream and toothpaste. Valio makes use of the heat generated by the mill in its cheese production. In 2018, Äänekoski town administration and its partners decided to create new CBE business opportunities as a response to the Bioeconomy Strategy. The business community has started to respond with new initiatives.

- EcoEnergy SF produces a unique biogas and biofuel pellets from the mill’s wastewater treatment plant sludge.
- Aqvacomp is exploring the possibilities to build a plant at Äänekoski based on its existing technology to process pulp into a biocomposite that can be used to replace plastic in the electronics and automotive industries.
- The mill’s sulphuric acid unit converts bad-smelling gases into sulphuric acid for the mill’s own use. It is the first sulphuric acid unit in the world to be connected to a pulp production process on this scale.
• A co-innovation joint venture between Metsä Group and Itochu Corporation of Japan to build a EUR 40 million test plant to de-risk and demonstrate a new technology for converting paper-grade pulp into textile fibres.

• Other typical pulp mill added-value products include tall oil (used in adhesives, rubbers, inks, soaps, lubricants, emulsifiers) and turpentine (used in solvents, paint thinners and fragrances).

• Gasification of tree bark into a bio-based natural gas, a biofuel to run the mill with no fossil energy at all.

• Even some of the CO₂ emissions from the plant will be captured and used for pigment production.

In this example is demonstrated classical industrial and innovation cluster behaviour: R&D networks, new de-risking joint ventures and creating added value by exporting of end products into world markets. The business concept for the bio-products will be built in collaboration with the partner network formed around the mill. The overall goal is to create bio-product concepts that use 100% of the wood raw material and the production side streams. It is expected to create some 2 500 new jobs, mostly in wood supply chains.

Source Adapted from OECD Observer (2019).

13.3.3. Regulatory barriers

The Finland case study in particular highlighted regulatory barriers. At an OECD workshop for this project at Ecomondo, Rimini, Italy on November 08, 2018, the same regulatory barrier was raised by almost all speakers: to properly align policy to make a CBE, it must be possible to use waste materials as feedstocks for biorefineries. However, in Europe there has been a significant barrier to doing this legally. This barrier had also been mentioned frequently at events during the two-year period of the project.

Policy measures are now being taken to remove this barrier. First of all, significant steps are included in the Waste Framework Directive (WFD to allow a more flexible use of ‘bio-waste’ (Accorigit, 2018):

• Article 22: By 31 December 2023 bio-waste shall either be separated and recycled at source or collected separately and shall not be mixed with other types of waste.

• Article 22.2: Member States shall take measures to: […] promote the use of materials produced from bio-waste.

The significance of these two articles is that there will be a provision for the separate collection of waste that can be used in biorefineries, and the second removes the barrier that has meant that a ‘waste’ has to be discarded, rather than being used as a secondary raw material.

Secondly, in the new Landfilling Directive (LFD):

• Article 5: ban on the landfilling of separately collected waste for recycling and preparation for reuse (including bio-waste).

The significance is that, even if using waste in biorefineries is a good example of circular economy and cascading use of biomass, landfilling in some countries may still remain
cheaper and therefore a preferred option rather than reuse or remanufacture. The ban on landfilling removes this option, paving the way for utilisation rather than disposal.

13.3.4. Coordination across agencies

Acceleration requires that different government agencies are not unintentionally at crossed purposes. In this respect there are lessons to be learned from the US experience. Several critical ideas are suggested but coordination at a more micro-level is also needed.

- Agencies and departments involved in technology push (e.g. innovation agencies) must be sure that they are not conflicting with market-pull agencies. The example of the USDA BioPreferred Program is especially relevant here, where public procurement for bio-based products helps create the market for the industries that produce them.

- The bioeconomy is encouraged for rural development, but the innovators may wish their products to pass on to national and/or global markets. Thus there is a strong need for coordination between national and regional government. Local and tacit knowledge and resources can easily be overlooked in capital cities.

- Using waste materials as feedstocks for bio-based manufacturing can interfere with established environmental markets, such as incineration and industrial composting.

- In particular, regulatory hurdles are to be avoided. For example, a research policy that encourages laboratory development of genetically modified bacteria for contaminated soil and water bioremediation would fail to create spillovers if national policy creates large barriers to the deliberate release of genetically modified organisms.

The case study from France highlighted hurdles that would not necessarily be envisaged by public sector actors and yet can create major barriers in the private sector. For example, the ARD biorefinery cited time required to gain authorisation to operate and to acquire the relevant construction permits for new plants. Also REACH registration of new products has to be completed by the company that will launch the products. This takes time and is expensive to finance and may have a direct impact on the competitiveness of these products compared to existing one. These are details that can be attended to through policy and agency coordination, but which also need foresight to anticipate. Dialogue with the private sector is therefore essential, and should be built in to the functions of publicly funded clusters.

- The bioeconomy spans several disparate industry sectors that classically may operate in silos. For example, it is relatively uncommon for the dairy industry to connect with the chemicals industry. Equally, there is a need for innovative policy-making to break down sectorial barriers.

- On the more global scale, this green transition also requires coordination with larger policy goals. In particular, it has been suggested that biotechnologies can address more than half of the Sustainable Development Goals (El-Chichakli et al., 2016). Nevertheless, these very biotechnologies are seldom given high priority in discussions of agencies such as the Intergovernmental Panel on Climate Change (IPCC).
13.4. The key role of demonstrator plants

The demonstrator phase is a critical stage on the way to commercialisation. Larger than pilot scale, economic and technical limitations often make themselves evident during demonstration. Rather than having to correct these limitations at full-scale production, they can be corrected in a much less costly way at the demonstration scale. Thus demonstrator plants are de-risking facilities, but their construction is unpopular as they may not have enough capacity to influence markets, and can end up being stranded assets.

Countries often refer to the lack of demonstrator funding as a barrier to commercialisation. Finland specifically mentioned this in the case study. One of the reasons behind setting up the Biobased Industries Joint Undertaking (BBI JU) in Europe was to encourage the construction of demonstrators as public-private partnerships (PPPs). In doing so, other policy issues are addressed, such as breaking silos between the relevant industry sectors. BBI JU, in financing these PPPs, does so on the basis that an entire value chain will be created.

Personal communications from BBI JU describe a catalytic effect – once companies realise demonstrator finance is available, other partners are more amenable to joining a project. Thus it can be said that a model such as BBI JU attempts to address the many commercialisation barriers in a holistic way, thus bridging “systemic challenge” gaps. The open access Pilots4U initiative in Europe expresses the situation very clearly (Box 5).

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**Box 5. Pilots4U, an open access pilot and demonstrator infrastructure.**

One of the main challenges in the bioeconomy innovation chain in Europe today is the step from technology to deployment, which in most cases require access to pilot and demo plants. Pilot and demo plants are, however, expensive industrial installations to which most companies do not have direct access. One solution is the ‘open access pilot- and multipurpose demo-infrastructures’, open to all companies and research institutes. Yet, there is a lack of awareness of the availability, type of facility and equipment modules these offer, which impedes actors from localising relevant facility. The aim of the Pilots4U project is to tackle these challenges and provide solutions that will support the development of innovations into products.

As the network will build on six of the partners’ existing bioeconomy pilot or multipurpose demo-infrastructure networks, it will assure the involvement of at least 40 infrastructures. These six partners of the Pilots4U project, and the networks they represent, are: Bio Base Europe Pilot Plant (SmartPilots), VTT (ERIFORE), Royal Institute of Technology KTH (BRISK2), Swansea University (Enalgae), Ghent University (Biorefine Cluster Europe) and NNFCC (as secretary of the BioPilotsUK initiative). The cluster organisation CLIC Innovation is representing industry that is contributing in cash to the project. The European Regions Research and Innovation Network with 140 member regions will attract interested European stakeholders (infrastructure owners and users) to get involved in the project, and NNFCC, the bioeconomy consultant, is a professional, independent consultant who will lead the study.

*Source: [https://www.biopilots4u.eu/content/about-us](https://www.biopilots4u.eu/content/about-us)*
13.5. The roles of public funding in clusters and other PPPs

The primary role of publicly funded clusters could be reducing the transaction cost of networking stakeholders who would not normally network together e.g. the dairy industry and the chemicals industry. It has often been said that a challenge for the bioeconomy is breaking the silos of the relevant industry sectors. Clusters and other forms of PPP are dominant instruments in this process to overcome systemic barriers. Some other bioeconomy clusters beyond those in the case studies were explored by Philp and Winickoff (2017).

Clusters formed a central theme of the case studies. Flanders has publicly funded clusters in a dominant role. Canada emphasised the role of Bio-industrial Innovation Canada in the diversification of the Sarnia-Lambton (pre-existing) cluster. Norway specifically described the use of demonstrator PPPs to grow clusters as de-risking instruments. In Italy, much more effort has been made by the private sector, but Italy has one bioeconomy-specific national technological cluster (Cluster SPRING) that plays several roles.

The Finland case study does not mention roles for clusters in the same way, but there are “a few open-access pilot facilities in Finland for the forest-based bio- and circular economy”, which can play similar roles in networking and de-risking. They were similarly less emphasised by Sweden although the roles of publicly funded demonstration plants were central to the case study,

China and Japan were case studies at a national level, and therefore clusters and demonstration and plants would be less likely to be emphasised as they were more guided by national policy. However, the Biomass Industrial Cities of Japan clearly contain examples of publicly funded demonstration plants, and each Town or City can be seen as an expanded cluster.

13.5.1. Regional versus technology clusters

Both have their roles to play. It seems counter-intuitive that technology clusters would arise and flourish in the rural environment if they are at a distance from learning and research organisations. However, in the bioeconomy local knowledge is vital due to the decentralised/rural locations. One cluster that appears to bridge the gap is the Industry and Agro-resource (IAR) cluster in France (Box 6).

Box 6. IAR and ARD in Northern France.

IAR is large, mature cluster, with 250+ projects, 370+ members and over EUR 1.7 billion in investments. It is involved in the set-up of several French and EU projects. Some of its activities are dedicated to support innovative start-ups to access funding to scale up their activities. It also provide business intelligence and develops targeted studies on bio-based products and processes.

It is supports several demonstration platforms and projects such as BRI (industrial biotechnology), IMPROVE (plant proteins valorisation), PIVERT (oilseed biorefinery) and Futurol (advanced biofuels) which are allowing companies to scale up and demonstrate their products and processes. IAR’s objective is to maximise the valorisation of renewable resources for food and non-food applications with a focus on four strategic areas: agro-materials, bioenergy, bio-based chemicals and ingredients.
IAR-Invest offers partnering services for companies with private investors, mainly those specialising in venture capital. It offers support in fundraising, and facilitates meetings with potential national/regional councils and public/private investors, funds, banks, incubators and financial institutions.

13.5.2. The importance of geography: linking to smart specialisation

The economic rationale for government intervention should define the programme targets. Those targets may be: places (e.g. leading or lagging regions); sectors (e.g. young growing, exposed, strategic and/or societally significant), or; specific actors or groups of actors (e.g. universities, SMEs, multinationals). Albeit in theory spatially neutral, in practice cluster policies often focus on specific geographic areas where key institutions, researchers and firms are clustered (OECD, 2007).

The approach is exemplified by an analysis of all regions of mainland France for their strengths and weakness, and lagging and leading regions with respect to smart specialisation (Commissariat Général à l'Égalité des Territoires, 2015). From this document:

“Each region is characterised by a specific context relating to unique socio-economic features. These specific characteristics determine their ability to adopt a smart specialisation approach as well as the way they appropriate this concept. These characteristics are therefore decisive in the definition and deployment of the French regions. Analysing a number of indicators helps to underline the economic and innovation diversity of the French landscape. It also helps distinguish defining territorial characteristics for the smart specialisation process: the role of employment in the production and industrial sectors, the sectoral concentration of the economic fabric, the employment trend, the size of the businesses, the number of students and researchers, the number of patents and the gross domestic expenditure in research and development”.

This document identified Toulouse, in the Midi-Pyrénées region, with two specialisations of interest: ‘industrial biotechnologies for the recovery of renewable carbon’, and ‘territorialised agri-food innovation’, which are a perfect match for a bioeconomy. Two of the strengths of Midi-Pyrénées of particular relevance here are research excellence (there are 110 identified research structures in the Midi-Pyrénées), and a dense network of transfer and support structures. Toulouse White Biotechnology (TWB) was granted EUR 20 million from the French government programme ‘Investissement d’Avenir’. As of 2018, TWB has a partnership of 30 companies (from start-up to large companies), 4 investors, 3 technology transfer partners and 9 public partners. It can be viewed as a preindustrial demonstrator for sustainable production based on industrial biotechnology.

13.5.3. Which level of government?

There are economic rationales for all levels of government (local, regional, national, and in some cases supranational) to support them. Which level of government does what in policy is determined by several factors (OECD, 2010). For example, does the policy align with a higher supranational competitiveness policy, with a national growth programme, or with a local employment hub for regions?

Industrial biotechnology is increasingly associated with national policy, for example, a national bioeconomy strategy. However, local government has essential roles to play in creating quality of life, by providing good infrastructure and utilities, quality local schools
and other ‘lifestyle’ facilities. This is especially important in a rural setting because an appropriate work/quality-of-life balance may be more difficult to achieve. Policy design should identify what is expected of each level of government.

13.5.4. Know the limits of public intervention

The public sector cannot exclusively drive cluster policy; Silicon Valley did not develop as a result of public sector investments. A large factor for success in a cluster is trust between private partners (Ketels, 2013). Several programme evaluations have noted an excessive public sector role and an unsuccessful exit strategy. The private sector is more adept at predicting business risks, and the public sector should not attempt to take a forefront role in their mitigation. Policymakers need to match expectations with resources and potential.

13.5.5. Cluster success depends on the future commitment of the private sector

The long-term survival of a cluster depends to a large extent on the private sector continuing to invest after direct public funding ends. Over-reliance on key companies is a related risk. The solution is diversification, drawing in different types of companies from different sectors (see, for example, the Äänekoski example in Box 4).

13.5.6. Value for money: metrics for clusters and other forms of bioeconomy PPP

Despite being a very common public policy instrument, cluster public financing is not universally accepted as a way to build out technology-based new industries. In the United States, for instance, there are many clusters, but they generally tend to be formed bottom-up by companies and entrepreneurs rather than by direct government intervention: government roles are more likely to be in enabling, facilitating, co-funding, and providing framework conditions. As these PPPs are relatively costly, it is therefore important that policymakers seek to discover what value they add and to measure their success.

At some of the workshops for this project it was asked of cluster and PPP employees if they thought that their parent public funding bodies ask the right questions when it comes to the evaluation of the cluster. It was clear that they often felt that this was not always the case. Part of the problem arises from the dislocation of the political cycle (around 5 years) from the innovation cycle (much longer). This requires dialogue between the policy makers and the policy implementers, and a long-term view robust against party politics.

Advice on assessing the effectiveness of a cluster is not clear because appropriate tools for quantitative assessment are not available. Kircher (2012) offered a set of key performance indicators (KPIs) for bioeconomy clusters applicable to other forms of bioeconomy PPP (Table 3).
Table 3. Suggested KPIs for bioeconomy clusters and other forms of PPP.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saving fossil energy</td>
<td>PJ per year; EUR per GJ</td>
</tr>
<tr>
<td>Saving CO2 emissions</td>
<td>EUR per tonne CO2 equivalent</td>
</tr>
<tr>
<td>Extra revenue of the agri sector</td>
<td>EUR million per year</td>
</tr>
<tr>
<td>Share of industrial feedstock produced</td>
<td>Percent</td>
</tr>
<tr>
<td>Value of industrial feedstock produced</td>
<td>EUR million per year</td>
</tr>
<tr>
<td>Share of bio-based energy and chemicals</td>
<td>Percent</td>
</tr>
<tr>
<td>Extra revenue in energy and chemicals sectors</td>
<td>EUR million per year</td>
</tr>
<tr>
<td>Import of bio-feedstock</td>
<td>EUR million per year</td>
</tr>
<tr>
<td>Impact on balance of trade</td>
<td>EUR million per year</td>
</tr>
</tbody>
</table>

Source: Kircher (2012).

It should be noted that Table 3 contains two very important environmental indicators that require specialist knowledge and tools for measurement (fossil energy and GHG emissions savings). Therefore policy makers should also take note of the requirement mentioned in the Norway case study for funding for techno-economic feasibility studies, especially for small companies.

Another important factor that currently seems to get too little attention is the effect on biodiversity. As the new bioeconomy leads to a competition for land, biodiversity and intact ecosystems (and food production) may be compromised. Policy in the bioeconomy should emphasise a balance between CO2 mitigation and biodiversity protection; hence a knowledge-based policy would also depend on LCA and assessment of the sustainability of biomass sourcing.

A very common metric is leverage i.e. how much private investment is leveraged given the initial public investment. It is important for the public funders to see this as a long-term effort for both the regions and the nation. Logically, longer-term leverage is likely to outstrip the shorter term leverage during the period of public funding. Therefore the clusters need to expend a lot of effort in bringing in private investors, but with a sensible balance of cash and in-kind contributions, both of which need to be considered as part of leverage.

13.5.7. Tap into other funding and investment sources

A cluster that becomes efficient at leveraging private investments has a better chance of survival when the public funding has run its course. Policy makers should be cognisant to design cluster programmes such that research institutions and companies can exploit other external R&D funding sources and programmes. This may draw in other private sector actors, decreasing dependence on key companies. Leveraging other private sector investments enables a successful public sector exit.

13.5.8. Encourage clusters to internationalise

Becoming international was discussed especially in the Flanders case study. Geographically, this is understandable, with its location within the Antwerp–Rotterdam–Rhine–Ruhr Area (ARRRA), the centre of European chemicals production is the triangle of Belgium, The Netherlands and Northwest Germany. The area is responsible for the production of two-thirds of Europe’s chemicals.

International agreements can bring several benefits – sharing of technology, mobility of people, and tackling international issues such as biomass sustainability, trade, and tapping...
into international funding programmes. One example is the 3BI (Brokering Bio-Based Innovation) inter-cluster is the result of four clusters joining forces: Biobased Delta (The Netherlands), BioEconomy (Germany), BioVale (UK), and IAR (France). Their goal is to support European companies to access important new bioeconomy markets.

13.6. The roles of modern biotechnologies and their alliance with computing and information technologies

While biotechnology and digitalisation is sometimes implied, only the United States has presented a case study with engineering (synthetic) biology as a major driver for the bioeconomy. Norway described critical technology gaps that can be filled by companies familiar to the United States case e.g. LanzaTech. During an OECD fact-finding mission to Finland in 2016, the lack of such companies was described as a gap in the Finland bioeconomy. Genomatica is another such US company that supplies specific engineered microbes at the core of some European bioeconomy initiatives.

In bioeconomy fora, there is often this divide, especially between the United States and European countries. The view in the United States is that biomass utilisation and product diversity can be enabled by engineering biology as a platform technology, from fuels to plastics, commodity chemicals, specialties, pharmaceuticals and others.

If countries need these modern biotechnology companies in their bioeconomy but have to look abroad for them, then there are questions for policy makers in R&D&I. Are the investment conditions wrong? What specific conditions are necessary to allow innovative yet high-risk biotechnology start-ups to survive? What is their relation to the greater goals of a bioeconomy, such as climate change mitigation?

The idea of public biofoundries as described in the US case study may hold answers that policy makers could study. Greater levels of automation, digitalisation and the introduction of engineering standards in biotechnology companies should lead to improvements in reproducibility and reliability. Indeed, an article in The Economist in 2018 went as far as to suggest that the biotechnology companies of the future could operate without expensive laboratories and equipment as biofoundries could do this work for them (The Economist, 2018), and in doing so “design of synthetic lifeforms could become a new industry”.

This presumably would lead to more effort being spent in biotechnology companies on design rather than manual execution of experiments. If so, then this is approaching the engineering design model that is essential to modern manufacturing, where design and manufacture can be done in totally separate locations (Kitney et al., 2019). This could also simplify the investment strategies for small, innovative biotechnology companies by negating the need for expensive infrastructure. Moreover, the US case study shows that the public biofoundry can itself be the hub of a growing bioeconomy ecosystem. Further exploration of public/private hybrid models is suggested (e.g. Gauvreau et al., 2018).

13.6.1. Coordination across different policy agencies

To embed such a policy strategy in government requires coordination of different agencies involved, from agriculture (e.g. biomass supply), to energy to R&D&I to industry. The discussion returns to supply- and demand-side measures. The US case study illustrates how different agencies are needed to coordinate policy action. There, the Department of Agriculture, the Department of Energy, the Department of Defence, the National Academy of Sciences, regulators and others are involved in developing the biotechnology-enabled advanced bioeconomy.
13.7. Where are the medium-sized companies?

Innovation policy gives particular emphasis to the needs to small-to-medium-sized enterprises (SMEs). Hence governments have become adept at policy support for start-ups and small companies. Growing these to medium-sized companies, however, deserves greater attention (a barrier by no means unique to bioeconomy companies). For example, eight out of ten Canadian bioeconomy companies have fewer than 50 full-time employees (BioTalent Canada, 2011).

Medium-sized companies can be small enough to be able to innovate quickly, yet large enough to contribute to manufacturing. This latter ability should be important to building bioeconomy ecosystems to leverage a critical mass effect. In many other industries, such as automotive, the medium-sized companies play a key intermediate role in the supply chain, but may remain “hidden champions” as they can have a large market share while their goods are invisible in the finished product (Tunisini and Resciniti, 2013). An ecosystem with too large a proportion of small companies compared to medium-sized could have a decreased capacity to bring products to the market in a timely fashion. This could also place too large a burden on a single key company.

There is a view that in the healthcare sector the business logic makes it very difficult for an innovative drug developer to grow beyond a certain size before they are absorbed by a larger company. Perhaps such a barrier will also exist for bioeconomy companies not in healthcare. There is a need for more extensive economic research on the drivers behind consolidation in the bioeconomy, such as high capital requirements and few strategic customers.

13.8. Skills and education, essential to maintaining vibrant ecosystems

Growing the circular bioeconomy and its bio-based industry is going to challenge higher education, especially with an emphasis on distributed manufacturing in rural locations. The bio-based industry, while still young, is growing. The global biorefinery products market accounted for USD 498 billion in 2017 and is expected to reach over USD 1 trillion by 2026, growing at a CAGR of 9.3% (Il Bioeconomista, 2018). One of the challenges for the education sector is to keep up a supply of suitably qualified graduates and postgraduates.

More than 35% of Canadian bioeconomy firms lack the full set of skills they require. An equivalent number say they cannot find appropriately qualified candidates and 55% need to outsource skills and tasks (BioTalent Canada, 2011). The Netherlands predicts the need for 10 000 bioeconomy experts by 2026 (Langeveld et al., 2016).

Building a bioeconomy workforce requires more undergraduates than PhDs, although a lot of discussion is about PhDs. Traditional scientific education and training has remained divided by disciplines such as microbiology, chemistry and computing. The long-standing conundrum of multidisciplinary education is the need for both breadth and depth to graduate people with problem-solving abilities. The challenges and some of the solutions were reviewed recently (Delebecque and Philp, 2018).

A further quandary for governments regarding educational aspects is that one route to training that is suggested is an apprenticeship training route to keep day-release apprentices from companies close to the training centres. However, a “tyranny of small numbers” has been identified in the UK, meaning that there is not a critical mass of apprentices in one geographical area to make it worthwhile for colleges to offer specialised industrial biotechnology courses (Lewis, 2016).
The ecosystems can help shape the agenda for the education of this future workforce. For example, BioCirce is the first European Master in Bioeconomy in the Circular economy. It is an initiative of four Italian universities with the support of key Italian bioeconomy players (Cluster SPRING, Novamont, GFBiochemicals and Science Park of Lodi) and the Italian leading banking Group Intesa Sanpaolo.

13.9. High biomass diversity, relatively low product diversity

The feedstock sources in the case studies span forest (timber, residues and side-streams), agriculture (waste and residues, food and non-food crops), domestic waste, marine resources (including fish waste) and waste industrial gases (not biomass, but a source of carbon for bioprocessing).

The envisaged fossil-replacing products are less diverse. Bioenergy (principally biogas) and biofuels (ethanol and biodiesel) are products described by Belgium (Flanders), China, Canada, Japan and Sweden.

For perspective, the chemicals industry collectively makes some 70 000 products; in the United States alone, the industry contributes over 5 million jobs (direct and indirect) and is the second-largest manufacturing sector accounting for about 10% of exports. However, it is also one of the largest energy consuming industries and among the highest GHG emissions producers.

While transportation fuels and electricity generation have been common targets for renewables policy, much can be done in chemistry to reduce emissions but there has been very little policy focus on renewables chemistry (e.g. Philp, 2015), of which bio-based chemistry is a component.

Despite chemistry being a cornerstone manufacturing industry in many OECD member states, they are losing global competitiveness to some non-member states. The transformation to bio-based materials has been cited as a means to reasserting competitiveness in chemistry in advanced economies.

Therefore there is more than one policy message here:

- Several case studies list climate change and climate obligations as a driver for CBE in the countries, and several mention higher value-added. Some, especially Sweden, emphasise reduction in dependence on fossil resources. There is something of a mismatch of the low diversity of products with these drivers

- For most of the larger economies of the OECD, the vital importance of the chemicals industry to their economies, combined with decreasing competitiveness, should highlight the need for exploring the possibilities beyond the current low diversity of products

- Using bio-based production to boost job potential is only part of the jobs story: it could also save highly skilled jobs in the chemicals industry while making the latter more competitive with low-cost nations

- Low-volume, higher value-added products have much lower impact on emissions reduction than would a bio-based equivalent of one of the top petrochemicals, such as ethylene, propylene, butenes, benzene, toluene, xylene, and syngas/methanol that largely dominate the petrochemicals market. This relates to an issue discussed in several OECD documents – scale in bio-based production is very difficult to achieve, and this has been behind PPP policy instruments to finance demonstrator
and full-scale flagship plants. Succinctly put, volume is needed for the societal goals of climate mitigation, while the high end differentiated products are necessary for value chain economics. It is typically very difficult to align high commercial value with high climate effect.
14. Digital and experimental approaches to ecosystems policy at three geographical levels

One of the greatest benefits of digitalisation is the ability of ICT to bring the bioeconomy ecosystems to a wider audience. To date, the term bioeconomy is still not well known in society. Two decades ago, an approach for governments to disseminate new technologies was the ‘roadshow’ approach. This involved civil servants and subject-matter experts literally travelling from city to city, holding events open to industry and the wider public. It is laborious and the audience reached is limited to the actual size of the venue and then word-of-mouth.

Setting up digitalised communities can work at several levels. Firstly, the potential audience is much larger. Secondly, it can be a platform for distribution of information about available grants, jobs, events, contracts. Such communities can also be a forum for public opinion. Hybrid models include the digital and physical event approach. Moreover, the approach is independent of geography, applicable from international to institutional levels.

14.1. Institutional level: Open Science at Neuro, Montreal

At a very focussed level, institutional open science is a model intended to accelerate research advances and reimage its role in the community. Gold contends that in the pharmaceutical industry the linear commercialisation model is an increasingly outdated and ineffective approach (Gold, 2016). With this in mind, the Montreal Neurological Institute (Neuro) launched a five-year experiment during which it is adopting open science across the institution, including all of its laboratories. While being the first institution to adopt an open science model across the entire spectrum of its research, it will also provide a window into the future applications of open science more generally.

The benefits are expected to extend beyond the institution itself into the wider community. Open science provides advantages over proprietary models of innovation in this respect by enhancing partnerships, lowering transaction costs, and encouraging local innovation. The model promises open sharing of results, with the exception of clinical data. Researchers can also access associated metadata, physical biological samples and other research materials. It is also hypothesised that Neuro's institution-based approach will draw companies to the Montreal region, leading to the creation of a local knowledge hub, with attendant jobs and attracting other firms with complementary specialities (Gold, 2016). This hypothesis is, of course, very familiar to the bioeconomy communities.

14.2. National level: the UK knowledge transfer networks (KTNs)

The UK KTN approach is explicitly directed to facilitating an open innovation system (Box 7). KTNs provide information about market and supply chain developments, carry out futures and roadmapping work to help create business strategies, and help network and find partners nationally (and internationally).
Box 7. The UK KTN approach to R&D&I community building.

Primarily KTNs facilitate connection and collaboration with the UK’s innovation communities to unlock new opportunities in key research and technology sectors. A KTN provides an online networking platform to enable free access to online tools in a secure and confidential setting to explore challenging issues and to provide access to different collaborations. As a single overarching national network in a specific field of technology or business application, a KTN brings people together to stimulate innovation – from businesses of any size, research organisations, universities, and technology organisations, to government, finance and policy. The increased level of networking and collaboration means a greater likelihood of spillovers.

Eighteen different industries in the UK are supported by KTNs. Two that are highly relevant to bioeconomy ecosystems are the Biotechnology and Sustainability & Circular Economy KTNs. Others are also relevant, the idea being that overall the KTNs form a “network of networks” that would be very difficult to recreate by any other method than using ICTs.

Moreover, each individual KTN can allow specific interest groups to narrow the range of focus of interests of the members. For example, The Synthetic Biology Special Interest Group (SynBio SIG) of the Biotechnology KTN helps to partner the UK’s growing synthetic biology industry with industrial collaborators, research base expertise, investment opportunities and funders. Members of the SIG can actively find initiatives and opportunities at the dedicated website (https://ktn-uk.co.uk/interests/synthetic-biology) and more passively via a monthly update sent out by email. Initiatives range from large funding opportunities to small grants of GBP 500 towards travel and accommodation costs for SMEs to attend, for example, brokerage events.

Source: adapted from Medhurst et al., (2014), and using specific inputs from the SybBio SIG website).

14.3. An international example: BSR Stars S3

Bioeconomy clusters are forming several international clusters that provide advantages as already discussed: sharing of technology, mobility of people, and tackling international issues such as biomass sustainability, trade, and tapping into international funding programmes.

BSR (Baltic Sea Region) Stars S3 is an international project that seeks to enhance sustainable growth opportunities in the Baltic Sea Region, focusing on the fields of bio-, circular and digital economy. BSR Stars S3 stimulates transnational and cross-sectoral partnerships, develops integrated innovation support infrastructures and innovation management tools, and increases the capacity of innovation actors to utilise smart specialisation strategies (S3).

Apart from rapid communication via the website (http://www.bsr-stars.eu/bsr-stars-s3/), BSR Stars S3 supports various forms of physical activities e.g.: bio- and circular economy matchmaking events; seminars to better connect Nordic research and technology organisations (RTOs); a two-day Arctic study tour for participants working within circular economy; publishing policy briefs.
14.4. Summary

Policy for experimentation to build radical, new niches is crucially important, but not sufficient. The fossil resource-based society is so deeply entrenched that the policy mix will also need to contribute to a process of destabilisation of existing locked-in socio-technical systems. This process can clearly be seen in the slow shift towards renewable energy, where policy intervention has been abundant. However, greater balance in the bioeconomy is required (Philp, 2015) and the same policy radicalism is needed across the many sectors that constitute the modern bioeconomy. In climate policy, for example, carbon price and taxation is at the forefront, and the many roles of research and innovation get less political coverage.

Many countries rely on publicly funding clusters for dissemination of new technologies, and this is common in bioeconomy policy. Whilst there are good examples of where this strategy is working to reduce the transaction costs of building networks, there is room for greater experimentation e.g. hybridising the cluster approach with investment mechanisms and new business models, building private or semi-private IROs (Gauvreau et al., 2018). Recommendations cannot be overly prescriptive, however, as each nation and each bioeconomy is different, although the need for policy experimentation is universal.
15. Concluding remarks

It remains to ask what the future holds if the policy implications of the described work in this report are not enacted. If transformation of the biggest sectors, such as chemistry, to a more sustainable model does not occur then meeting climate targets become more difficult. On the larger stage, societal inequalities become more severe, consequences of climate change and pollution begin to hit harder, migration becomes more difficult to manage. Even popular unrest and armed conflict cannot be ruled out. At the time of writing the Swedish teenager Greta Thunberg has become a global phenomenon after her climate strike outside the Swedish parliament in 2018 and by speaking at the UN and Davos. This has inspired thousands of other young people across the world to carry out similar protests.

Building regional and national bioeconomies is proving to be difficult. Joining them to make an international (circular) bioeconomy represents a major transition for society, away from fossil dependence and towards a more sustainable economy and future. The policy mix reflects both the complexity and the importance of this transition. There are many facets to be tackled in policy. Previous work at the OECD has looked at various industrial and technical models.

Science, technology and innovation will have to be part of this response, but it makes less sense to respond through isolated national systems of innovation rather than through collective action. The roots of the bioeconomy are in this transition to a more sustainable society. However, many questions remain about the sustainability of a bioeconomy as well, and in particular there is a societal contradiction that needs to be addressed: increasingly society seeks solutions to the grand challenges, while in many parts of the world there is resistance to biotechnology which holds many solutions. This contradiction is starkly illustrated by attempts to engineer many crops to fix nitrogen from the atmosphere. The potential environmental and social benefits of replacing mineral fertilizers are plain to see, but resistance to GM crops remains persistent in some parts of the world.

The bioeconomy is now much wider than the economic contributions of the life sciences. At its foundations is the much increased use of biomass and industrial gases as feedstocks for future manufacturing. National and international efforts to build the industrial ecosystems could return jobs to rural areas, enable the distributed manufacturing paradigm, reduce inequalities and address the grand challenges that seem so intractable. But great care needs to be taken that an unsustainable fossil economy is not replaced with an unsustainable bioeconomy. For the policy maker, this is where the combination and hybridisation of conventional R&D&I policy has to meet the experimental.
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Endnotes

1  https://www.bincanada.ca/
2  BioAmber financial status is currently (July 2019) unpredictable.
3  https://www.biopreferred.gov/BioPreferred/
4  http://masterbiocirce.com/
5  https://www.energy.gov/eere/amo/chemicals-industry-profile