Current situation and trends of the bio-based industries in Europe with a focus on bio-based materials

Pilot Study for BBI JU

nova-Institute
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AFV	Alternative fuel vehicle
API	Active pharmaceutical ingredient
B2B	Business-to-business
BBI-JU	Bio-based Industries Joint Undertaking
BBMC	Bio-based Materials and Chemicals
BDO	1,4-butanediol
BIC	Bio-based Industries Consortium
BISO	Bioeconomy Information System and Observatory
BS	Biosurfactant
CAGR	Compound Annual Growth Rate
CCU	Carbon Capture and Utilization
CEFIC	European Chemical Industry Council
CDU	Carbon dioxide utilization
CO_2	Carbon Dioxide
CTO	Crude tall oil
DIN	German norm (Deutsches Institut für Normung)
DNA	Deoxyribonucleic acid
EAV	Economic added value
EC	European Commission
EN	European Norm
EU / EU-28	European Union
EUROSTAT	European statistical database
EV	Electric vehicle
FAO	Food and Agriculture Organization of the United Nations
FDCA	2,5-furandicarboxylic acid
FTE	Full time equivalent
FQD	Fuel Quality Directive
GDP	Gross Domestic Product
GHG	Greenhouse gas
GMO	Genetically modified organism
GNI	Gross National Income
HEC	Hydroxy-ehtyl cellulose
IB	Industrial Biotechnology
ICT	Information and communication technology
IEA	International Energy Agency
ILUC	Indirect land use change
IP	Intellectual property
IPCC	International Panel on Climate Change
ITC	Investment tax credit
JTI	Joint Technology Initiative
JRC	Joint Research Centre (of the European Commission)
LCA	Life Cycle Assessment
LMI	Lead market initiative
MC	Methyl cellulose
MDF	Medium-density fibreboard

MEG	Monoethylene glycol
MS	Member State
NACE	Statistical classification of economic activities in the EU
NFC	Natural fibre composites
NHA	Net harvested area
NGO	Non-governmental organisation
NREAP	National Renewable Energy Action Plan
OECD	Organisation for Economic Co-operation and Development
OEM	Original equipment manufacturer
OSB	Oriented strand board
PA	Polyamide
PBAT	Polybutyrate
PBS	Polybutylene succinate
PCL	Polycaprolactone
PDO	Propanediol
PE	Polyethylene
PEC	Primary energy consumption
PEF	Polyethylene furanoate
PET	Polyethylene terephthalate
PGEC	Plant Gene Expression Center
PHA	Polyhydroxyalkanoate
PHB	Polyhydroxybutyrate
PHBV	Poly(3-hydroxybutyrate-co-3-hydroxyvalerate)
PLA	Polylactic acid
PLGA	Poly(lactic-co-glycolic acid)
PP	Polypropylene
PPC	Polypropylene carbonate
PPF	Polypropylene fumarate
PPI	Pulp and paper industry
PRODCOM	Production statistics of the EU
PUR	Polyurethane
R&D	Research and development
R&I	Research and innovation
RDI	Research, development and innovation
RED	Renewable Energy Directive
REDII	Renewable Energy Directive after 2020 (proposed)
REMD	Renewable Energy and Materials Directive
RES	Renewable energy source
RUC	Resource use change
SIDS	Small Island Developing State
SIRA	Strategic Innovation and Research Agenda
SME	Small and medium enterprise
SWOT	Strengths, Weaknesses, Opportunities, Threats
TEE	Techno-economic evaluation
ToR	Terms of Reference
TPS	Thermoplastic Starch
UK	United Kingdom of Great Britain and Northern Ireland
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme

UNFCCC	United Nation Framework Convention on Climate Change
US	United States of America
USD	US Dollar
USDA	United States Department of Agriculture
USP	Unique Selling Point
VAT	Value Added Tax
VC	Venture Capital
WPC	Wood-plastic composite
WTP	Willingness to pay
WWF	Worldwide Fund for Nature

1 Executive Summary

The “Study on current situation and trends of the bio-based economy in Europe” carried out a meta review of the existing research on different topics and sub-topics relevant to the bio-based economy. The final objective of this exercise was to enable BBI JU to carry out targeted business intelligence activities to illustrate the socio-economic and environmental impacts, as well as the most important drivers and trends of the bio-based economy. Overall, approximately 200 studies and reports were assessed[1] dealing with the following topics:

- Products and markets
    - Automotive
    - Textiles
    - Medical, healthcare and pharmaceuticals
    - Home and personal care
    - Food and feed additives
    - Construction and furniture
    - Packaging
    - Pulp and paper
    - Bioenergy and biofuels
- Socio-economic aspects
    - Employment, turnover, GDP
    - Public and private investment
- Climate change mitigation and environmental aspects
    - GHG emission reduction
    - Organic residues as feedstock
- EU policies and regulations
- Research & technologies
- Global trends
    - International markets
    - Policies and initiatives outside the EU
- Social benefits & consumer acceptance
    - Consumer awareness, acceptance and trends
    - Improved product functionalities

The availability of knowledge is very different, depending on the topic. For some chapters, we were able to find an abundance of studies, while for other there was hardly anything to evaluate. Each sub-chapter provides an overview of the assessed studies (in form of a table) and an analysis of the main findings and trends, followed by a gap analysis and recommendations for further research, if deemed necessary.

Markets and products

Automotive: Biocomposites, wood and natural fibres reinforced plastics, natural rubber and some high-performance bio-based polymers are established materials in the automotive industry. The main reasons to use bio-based materials are good cost-performance ratio or

[1] The Bioeconomy Report 2016 was published after the deadline of the final report of this study, so it could not be included of the scope. It is recommended as a source of general knowledge though and can be accessed via https://biobs.jrc.ec.europa.eu/sites/default/files/generated/files/stakeholders/JRC_Bioeconomy_Report2016_FINAL_web.pdf.

unique properties. The automotive sector does not see itself as being part of the bio-based economy; "bio-based" is not a driver, so consequently, there are no targets to increase the bio-based shares.

Without any supportive framework conditions, a slow increase in different sectors is expected due to improved properties and cost reduction in processing. With an increasing oil price, the development could speed up.

Textiles: The bio-based share in textiles fibres has been continuously decreasing since decades, mainly because of the limits of the cotton production and the progress and cost reduction in synthetic fibres. Wood-based fully integrated biorefineries are a big opportunity to produce cellulose textile fibres at high volumes together with chemicals, fuels and even food/feed additives. In addition, new bio-based polymer fibres will be introduced to the market. This way, the share of the bio-based in the textile industry can grow again.

Because the discussions around bio-based economy have mostly ignored the huge market for textile fibres so far, nova experts recommend the development of a European textile fibre strategy to promote the sector adequately.

Pharmaceuticals: One of the major trends in the pharma sector is that separate disciplines vanish more and more in the bioeconomy. This is generally interpreted as a positive thing, because it promotes synergy. As an example, industrial biotechnology can use various biomass feedstocks to produce, via fermentation, different molecules, such as restriction enzymes or ligases. These are needed to enable various omics technologies such as deep sequencing, in which the molecules are utilised in order to cut genes, for example. This in turn facilitates the development of better health through e.g. personalized medicine approaches to e.g. cancer therapy on the one hand. On the other hand, producing more and more active pharmaceutical agents using biomass instead of fossil materials should have positive effects on agriculture and the environment, which in turn can improve people's health.
Based on our experience, nova's experts estimate that other future markets for bio-based molecules in the pharmaceutical sector, apart from enzyme production, will be biodegradable bio-based polyesters, which can be used e.g. for tissue engineering applications, drug-delivery solutions and last but not least bio-based molecules that have e.g. antimicrobial properties themselves like some rhamnolipids.

Personal and home care: The market for bio-based alternatives in the home care sector is well developed compared to e.g. the bio-based intermediate chemicals market. One reason to explain this phenomenon is that the personal care market is generally characterized by consumers willing to invest more in otherwise comparable products. Furthermore, having an air of "nature/organic" gives bio-based options an extra USP, especially, when it comes to products touching the clients' skin, in addition to providing them with a "green consciousness". One trend should be further market growth for bio-based oils (used for e.g. emulsion formulations) which already have a long standing tradition of faring well, especially in the personal care sector. Further technological and market development of biotechnologically (meaning here to particularly include fermentation) produced surfactants such as rhamnolipids, which can also offer better performance to consumers, should be the biggest trend and market disruption we expect to see in the coming years.

Food and feed additives: Though there are a large number of studies in the area of researching different food and feed additives categories like antifoaming, antioxidant, emulsifiers and other, there are lack of studies to integrate these into bioeconomy. However, food and feed additives have been a key mention in almost all the bioeconomy papers published by a specific country or as whole at the European level, being described as strategically important

or having a big potential. It is quite interesting that there are numerous general claims about the strategic potential of this class of materials, while there is so little knowledge available on volumes, markets, economic and technological feasibility, value chains and resources. In the opinion of the authors of this report, it might be worthwhile to investigate more.

Construction and furniture: "Construction and furniture" are the second biggest bio-based sector in the economy after "Pulp and Paper", in terms of turnover. Wood is by far the most important bio-based material in construction and furniture. Also, traditionally wood was the most important construction material next to minerals, and for sure the most important in furniture.

Wood- and bio-based construction materials have a positive, environmental and health friendly image in the public. They are considered natural and green materials. Sustainable buildings have often a high share of bio-based materials, especially in the interior. With the discussions about circular economy and cascading use of biomass in the last years, there was an increasing interest in bringing more wood in construction instead of using it just for bio-energy.

Improvement in wood processing, new construction concepts for timber, newly developed paints and glues, insulation materials and biocomposites offer new products and allow additional applications. Further growth is expected, especially in wooden multi-storey buildings and through combination with industry 4.0 technologies.

Unsuitable standards and norms are still a barrier for the further market growth of bio-based constructions products.

Packaging: The packaging sector is the largest application sector for plastics in general. Bio-based drop-in plastics can lower the environmental footprint of plastic packaging and can be fully recycled. Biodegradable and compostable plastics offer additional end of life options for certain applications. Italy and France favour the use of biodegradable and compostable plastics through legislation, other countries do not see this as an option. So far, there is no common understanding, agreement or strategy in Europe on the question which bio-based and/or biodegradable plastics can and should play a role in sustainable packaging and the circular economy. The understanding and political framework differs from one member state to the other. The correlation between framework conditions and market success of bio-based packaging is very high and also strongly affects future projections. Biodegradable plastic markets have become political markets to a large extent.

Bio-based paper and board packaging show an ongoing growth because of price, properties and an established collection and recycling system in many member states. Further growth is expected with new and advanced paper and cellulose fibre packaging materials. See also next chapter.

Pulp and paper: In terms of volume, infrastructure and biomass supply, the pulp and paper sector is and will be one of the most important parts of the bio-based economy. In fully integrated lignocellulosic biorefineries, pulp and paper will only be one output. At the same time, a wide range of cellulose fibres, chemicals, fuels and food/feed additives can be produced, leading to a high resource efficiency of the wood utilization.

The worldwide demand for environmentally friendly packaging and hygiene papers will grow strongly. New technologies allow to enter even additional applications in packaging (for example shopping bags) and hygiene papers. The political debate about microplastics in the marine environment will put pressure on plastic solutions and strengthen the demand

for paper-based packaging and hygiene papers. Pulp and nanocellulose can also be used in combination with (bio)plastics in biocomposites for example for furniture or toys.

Bioenergy & biofuels: The bioenergy/-fuel sector seems to be the one of the most researched and covered areas. On the technological side, jet fuels seem not to be able yet to create a technology push but still rely heavily on policies to promote their use. The food vs fuel debate remains a hot-button issue. Nonetheless, more and more scientific publications indicate that biofuels are not as detrimental to food security as is widely believed (e.g. Locke 2013, Langeveld et al. 2013, Kline 2016). The issue is still a complex one and conclusions need to be drawn carefully. Whether wood-based energy can really alleviate climate change remains to be seen, as discussions on this topic are extremely controversial at the moment. It is problematic that most of the 'evidence' heavily relies on assumptions and modelling results, which make it almost impossible to pinpoint one correct claim.

Based on the mentioned discussion it seems to be reasonable to assume that the growth of the biofuel/-bioenergy share in the EU energy mix will heavily depend on the degree of subsidies they might receive. This high degree of uncertainty might hinder the further development of the bioenergy sector, because this translates into lack of security for investors. The heated comments on the Commission REDII proposal from November 2016 issued by different industry associations testifies to this fact. Another factor might be that valuable, renewable alternatives to biomass-derived energy exist and that technological advances make the material use of biomass more economically attractive for an increasing number of feedstocks compared to simply burning it or converting it to fuel.

Socio-economic aspects

Employment, turnover and GDP: The socio-economic effects of bioeconomy are not very well known as a whole. There are a few sector-specific studies on the wood processing and the pine chemicals industries or on the Industrial Biotechnology sector in Europe. The other studies looking at bioeconomy as a whole are either focused on a certain member state (so far, Germany and the Netherlands are the only countries where such studies could be found) or on Europe. For Europe as a whole, nova-Institute and the JRC are the only players providing data so far and they collaborate closely to offer consistent information.

All studies assessed in this report found positive contributions of bioeconomy towards value added generation and job creation in the EU. Those studies that executed a comparison between material uses and energy uses of biomass conclude clearly and unanimously that the material uses create much more value added and employment per tonnes of biomass and also in total than the energy sectors can. This is mostly due to the longer and more complex value chains of the material usages (CEPI 2011, Rajendran et al. 2016). Several studies also point out that material uses of biomass enable GHG emission savings at the same level or at even higher levels than the energetic use of biomass and could thus reduce costs of GHG abatement. None of the studies contain a calculation of GDP share of bioeconomy.

This study also provides a new estimation of employment and turnover figures, carried out by nova-Institute as primary research in this study (only exception from the meta review methodology). This calculation comes to the conclusion that the bio-based economy (excl. food & feed and also excl. the agricultural sector) accounted for € 674 billion in turnover and 3.3 million persons employed in 2014.

Public and private investment: There is very little information freely available when it comes to investment in the bioeconomy. Apart from the often-quoted 3.7 billion € investment to be made by BBI from 2014-2020, of which 2.7 billion € have been pledged by the industry and 1 billion are public investment, the only other figures on absolute amounts of investment were to be found in the commercial report by Lux Research, quoting $9.2 billion of funding attracted globally by bio-based chemicals and materials from 2010-2015. An older study by nova-Institute found indications that while investments in Europe and the US cover mostly R&D as well as pilot scale facilities, investments in Asia and South America are often on a larger scale and target commercial production plants. Two studies found that tax incentives and easy access to feedstocks are the main motivations for investors to build commercial plants outside of Europe. On top of the pledges made within the BBI, BIC's annual survey showed that its members had around €2 bn investments in Europe in the pipeline in 2015. This increased to €4 bn in 2016, and around €4.5 in 2017. It is unclear to which time horizon "in the pipeline" refers (personal communication).

Climate change mitigation and environmental aspects

GHG emission reduction: There are only very few studies that aim to provide a comprehensive overview of the complex connections between bioeconomy and climate change. This means that each study's conclusions are very dependent on the selected examples, assumptions, allocations and other methodological decisions, which makes it difficult to transfer their results to general claims. LCA methodology is an important cause for this problem, since it makes it necessary to decide on clear system boundaries, make assumptions and compare impacts with specific counterparts for each product.

It is therefore close to impossible to come to a unanimous conclusion about the environmental impact of bioeconomy as a whole which is made up of so many feedstocks, applications and pathways. The studies marked in green in Table 23 make an attempt to provide at least an approximation of such conclusions.

However, a few conclusions can be drawn with some confidence: To realise the full climate mitigation potential of bio-based products, biomass production in agriculture and forestry needs to be improved by:

- using sustainable agriculture intensification, e.g. precision farming and soil and water conservation; and other climate-smart agriculture practices; and
- avoiding direct and indirect land use changes. (Carus 2017)

This can only be achieved with:

1. a deeper understanding of natural capital and related changes (Marchetti et al. 2014);
2. the improvement of governmental, scientific and public participation in decision-making processes (Marchetti et al. 2014) and

further investment in research technologies.

Organic residues as feedstock: Current efforts on under-exploited residues and technologies focus on improved green methods to reduce waste volumes. However, when no further waste savings can be achieved, policy aspects seem to play a major role in ensuring these disruptive technologies can be successfully exploited. Positive impacts can be achieved under a clearer reframing of waste as by-product and focus on cascading. Nonetheless, any resource use change can have inadvertent consequences.

EU policies and regulation

There is a large number of studies discussing policy issues around the bioeconomy. The most often found topics are:

1. The lack of a level playing field between energy and material uses.
2. Access to market by bio-based materials.
3. Public procurement
4. Biodegradability, cascading use and circular economy

There is a number of recommendations of what to do about the level playing field, but they have not been taken to implementation by policy makers. Similar things can be found for the access to market. Regarding public procurement, both LMI recommendations have not really been implemented on a EU level. While some Member States have started pilot projects on bio-based procurement, there is no binding preference for bio-based products and no official EU sanctioned product list. Therefore, significant commitment and resources are still required to make progress on this topic.

The evidence base around the nexus of biodegradability, best end-of-life option and policy design for plastics in a Circular Economy is still lacking. Further research is needed to inform policy making on this issue.

Global trends

International markets: The production capacity of bio-based polymers is growing worldwide, but since 2015 only with the same speed as the total polymer market. So there is a constant share of about 2% of biopolymers in the total polymer market and no further replacement of petrochemical polymers foreseen as of now. The main reasons are low oil prices, low political support and a slower than expected growth of the capacity utilization rate.

Most investment is going to the core of the bioeconomy: bio-based building blocks and platform chemicals. The capacities show about 8% yearly growth. Based on this, new building blocks, new bio-based polymers, coatings, surfactants and others will follow. World market shares are expected to remain relatively stable, with Europe and the US staying on the same level, while Asia wins a little and South America loses a little.

Data on these developments are rare. Only commercial reports of very different quality are available for the production capacities of bio-based building blocks and biopolymers. Regarding other bio-based materials, the data situation is even worse. Some of the commercial reports have free available summaries. Data on the production are not available. So only some international experts can estimate production and trends.

Policy initiatives outside the EU: As awareness of the bioeconomy's potential spreads, there is a great number of countries that are somewhat engaged in the development of a national strategy. The main emphasis is often to enhance the economy of a nation and provide new employment and business possibilities, whereas the aspects of sustainability and resource availability are addressed only to a limited extent. This is achieved, across the globe, by nations investing in Public/Private Partnerships to expand their bio-based economy for domestic and international consumers.

If governments wish to realise a successful bioeconomy in the future, the case for supporting the production of bio-based chemicals and plastics, apart from biofuels, warrants serious attention. This is because a holistic approach to policy is more likely to lead to a successful

bioeconomy, with governments avoiding creating policies in one area that may create policy problems elsewhere.

Globally speaking, one option is to apply the policy support measures that are currently available to biofuels and bioelectricity to bio-based materials. The major policies that are most likely to stimulate investment in bio-based materials are quotas/mandates and tax incentives. Public procurement acts as a demand-side measure to stimulate market uptake. Another, potentially very effective, measure would be a planned phasing out of fossil fuel consumption subsidies.

As discussed in other chapters too, there is a considerable gap in data on the impacts of the bioeconomy as a whole, even in Europe. This makes information gathering even more difficult for countries and regions in which bioeconomy is not covered by a publicly established policy. Some specific information on the markets of individual product groups can be found, depending on the activities of market researchers or industry associations, for example. Language barriers (e.g. for the Chinese market) pose another challenge.

Research and technologies

Depending on the concrete definition, experts count about 40 biorefineries in the European Union, mainly sugar, starch and oil-based, which have been running for decades. The webpage "Commercial Biorefineries in Europe[2]" gives a very good overview on biorefineries in Europe:

- Starch- and sugar-based biorefineries: 21
- Oil-based biorefineries: 6
- Lignocellulosic-based biorefineries: 4
- Pulp biorefineries: 1
- Grass-based biorefineries: 1
- Syngas-based biorefineries: 1

Together, this amounts to 34 biorefineries. In addition, 6 flagship biorefineries have been funded by BBI, so in total 40 biorefineries are in processing or under construction.

A higher resource efficiency in biomass utilization and saving greenhouse gas emissions have been the main drivers for all biorefinery technologies and different new plants that are currently at pilot, demonstration or commercial scale. The resources that are being considered are all kinds of biomass: first generation feedstocks such as sugar, starch and vegetable oil as well as second generation feedstocks such as lignocellulose, biowaste, algae, syngas and biogas.

Successful and mature technologies are mainly the ones that utilise sugar, vegetable oil and pulp. The lignocellulose based refineries that are based on fermentation are still at a demonstration scale and most of the current research is directed at these lignocellulose-based refineries. The biorefinery concepts such as biogas-based, or algal-lipid-based are still at a descriptive level or ready for proof of concept.

According to the studies, the degree of maturity of the biorefinery concepts, both between themselves and with respect to the different sub-concepts, is very heterogeneous.

[2] https://biorrefineria.blogspot.de/p/listado-de-biorrefiern.html?m=1

Social benefits and consumer acceptance

Consumer awareness, acceptance and trends: Most studies assess the level of familiarity of consumers with bio-based products. The findings indicate that although especially in the newer studies more and more respondents are aware that the term ‘bio-based’ refers to the feedstock base (e.g. 60% of respondents in Kainz 2016), there is still a lot of confusion about the exact meaning of the term as well as its implications. Predominant issues that are often automatically associated with ‘bio-based’ are for example ‘biodegradable’ or ‘organic’ (the latter being a definite issue with German consumers; for other countries this has not been well established).

A number of studies tries to assess the acceptance of consumers of bio-based or green products by evaluating their willingness to pay (WTP) higher prices for such products. This higher price is also called “GreenPremium”. Almost all studies found a WTP higher prices, both by end consumers as well as by businesses in the value chain of bio-based products. Kurka 2012 found a WTP of 8%-15% more than the usual price for a bio-based product, while Carus et al. 2014 assessed the most acceptable GreenPremium in several bio-based value chains to be between 10-20%. Results on acceptance indicate that most of consumers’ positive associations with bio-based products lie in the areas of environment, sustainability and health. However, also the negative associations are similar: Price and product quality are predominant concerns, but also scepticism about claims seems to be an issue. The latter was also found in Lemke & Pereira Luzio 2014 as a general issue among green consumers. However, the general tenor of the analysed studies is that most consumers see bio-based products overall positively.

The most important trend seen among consumers in general is a trend towards more ecologically conscious, ‘sustainable’ consumption. This goes hand in hand for increased information requirements about products in order to make an informed buying decision. Seeing as the topics of environmental friendliness and sustainability seem to strongly influence the discourse with consumers, the topic of information requirement is therefore highly relevant.

Improved product functionalities: Apart from the topics of plastic packaging additives such as resin binders, the studies are lacking in a wide range of areas on bio-based products as functional products. The studies mainly focus on applications listed in previous chapters such as packaging, construction, textile and automobile, but not on the functional properties of chemicals such as dispersion agent, rheology modifiers, defoamers etc. The often-repeated claim that bio-based products offer additional functionalities to end consumers could not be substantiated by scientific studies within the scope of this report. As of now, the evidence base is mostly restricted to claims by companies, but not supported by independent third-party scientific research. In a multitude of cases, this is completely justified, since safety, environmental and functionality issues are often regulated through well-established industrial processes, such as REACH, safety certifications and others. Here, it might be more an issue of communicating these to the consumers and the wider public in a credible way. In some other cases, e.g. when it comes to biodegradation, the authors suggest that better guidelines and research are necessary.

This identified gap provides ample opportunity for follow-up and extended research. If added functionalities could be independently confirmed through research, this would facilitate both consumer communication and policy design – which could even lead to improved legislation on e.g. environmental issues that can be beneficial to the bio-based industries.

Disclaimer: The opinions expressed in this report are those of the authors and do not necessarily reflect the opinion or the position of the Bio-based Industries Joint Undertaking.

2 Goal, Scope and Methodology

This report presents the results of the study on current situation and trends of the bio-based industries in Europe, carried out by nova-Institute for the Bio-based Industries Joint Undertaking (BBI JU).

The study's goal is to provide BBI JU with an overview of the existing research on different aspects of bio-based industries in Europe. For this purpose, the study followed the definition of bioeconomy as "an economy using biological resources from the land and sea as well as waste, including food wastes, as inputs to industry and energy production. It also covers the use of bio-based processes to green industries"[3]. Within this large economic system, a smaller part is often called "bio-based industries". This comprises industrial and energy uses of biogenic carbon, but excludes the primary production of agricultural, forest or marine biomass and biomass used for food and feed purposes. This study focuses on the "bio-based industries". In the case of food and feed, only industrially produced additives are covered. The final objective of this exercise was to enable BBI JU to carry out targeted business intelligence activities to illustrate the socio-economic and environmental impacts, as well as the most important drivers and trends of the bio-based industries. In order to do this, it is first necessary to identify the existing knowledge and the corresponding gaps. Based on this first assessment, BBI JU will be able to carry out further, more targeted research for its objectives.

To this end, each chapter in this study consists of

a) a table with all publications relevant to the specific topic of the chapter, incl. a synopsis of each publication; and

b) an overarching analysis of the assessed studies which highlights recurring topics, identified trends and main findings as well as an overview of the main questions and remaining knowledge gaps.

The scope of the research is on studies and reports, not on primary documents (e.g. policy documents and bioeconomy strategies are out of scope). According to the ToR, only studies from 2012 onwards were considered; however, a few exceptions were made for 'milestone' studies carried out before 2012 that provide very important insights into some aspects of the bio-based industries, if similar research for a specific topic had not been repeated later on. In accordance with this scope, the presented study is a meta-review of existing research and does not carry out primary research. The only exception of this is the chapter on socio-economic impacts, in which nova has applied its own methodology (previously published with the JRC and with the Bio-based Industries Consortium) in order to assess turnover and employment effects caused by the bioeconomy and the bio-based industries, in addition to a review of other existing research.

This study is a pure desktop study. In a first step, we reviewed the extensive inventory of studies known to the nova team based on our far-reaching experience with the different topics with relevance to bio-based industries. These were supplemented with targeted research for further studies if a topic was not covered thoroughly enough, mostly with Google, Google Scholar, in the dedicated news platform news.bio-based.eu and through scientific journals and magazines.

[3] European Commission 2012: Innovating for Sustainable Growth. A Bioeconomy for Europe.

3 Markets and products

3.1 Automotive

Table 1: Studies relevant to the automotive sector

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	The development of instruments to support the material use of renewable raw materials in Germany (Summary) Market volumes, structure and trends – Policy instruments to support the industrial material use of renewable raw materials, May 2010	Carus, M., 2010	Comprehensive report on the development of instruments and measures, incentive systems, legislation to support the material use of biomass. This includes also recommendations for the automotive sector.	Long version only available in German, English short version available.[4]
2	The Bio-Based Materials Automotive Value Chain	Center for Automotive Research, Hill, K. et al., 2012, USA/Canada	Comprehensive report on bio-based materials in the North-American Automotive industry, covering fabrics, adhesives, reinforcement fibers, polymers, biocomposites. Technologies, properties, economic and political framework, most important players in research and production.	Outstanding report, something like this is not available for Europe.
3	Market Opportunities for bio-based composites	Haider, A., 2012	Technologies and markets for WPC & NFC, biocomposites in automotive and other applications. High market shares for press moulded party, opportunity for injection moulding and extrusion.	
4	Noch lange nicht ausgereizt	Klusmeier, W., 2012	NFC in automotive applications, main benefit: light weight; further market growth expected because light weight and lower energy consumption is an ongoing trend.	

[4] http://bio-based.eu/publication-search/?wpv_post_search=The+development+of+instruments+to+support+the+material+use+of+renewable+raw+materials+in+Germany&wpv_filter_submit=

5	Indulge & Explore Natural Fiber Composites An invitation to product designers	Tambyrajah, D., 2015	Comprehensive information and overview on biocomposites in different applications, technologies, design and product examples (many pictures).	
6	Life Cycle Impacts of Natural Fiber Composites for Automotive Applications	Boland, C. S., 2015	LCA for Kenaf and cellulose fibre in automotive biocomposites. For cellulose fiber composite components implemented on the range of vehicles, the substitution results in a life cycle energy savings of 6.5% to 7.4% and a GHG savings of 16.0% to 16.4%, when compared to the baseline component, without powertrain resizing.	
7	Wood-Plastic Composites (WPC) and Natural Fibre Composites (NFC): European and Global Markets 2012 and Future Trends in Automotive and Construction	Carus, M. et al., 2015	Comprehensive technology and market study on the use of WPC and NFC (biocomposites) in the European automotive industry. Status for 2012 and outlook 2020. Future market volume strongly dependent on political framework. Today: No support from policy except research support. Main driver today: Lightweight construction. Main application today and tomorrow: Press moulded interior parts with wood and natural fibres.	Different short versions of this report are available here:[5]
8	Nachhaltig nutzbare Potenziale für Biokraftstoffe in Nutzungskonkurrenz zur Lebens- und Futtermittelproduktion, Bioenergie sowie zur stofflichen Nutzung in Deutschland, Europa und der Welt (Schlussbericht zum Vorhaben)	Piotrowski, S. et al., 2015	This report covers all demand sectors for bio-based industries including material markets in 2011, 2013 and 2050. This also includes an analysis for the growing demand in the automotive sector and especially the demand of rubber (tires and other parts), bio-based plastics and composites.	Long version only available in German, English short version available.[6]
9	The European Hemp Industry: Cultivation, processing and applications for fibres, shivs, seeds and flowers	The European Industrial Hemp Association (EIHA), 2016 (also older versions from 2013 are available)	Hemp fibre reinforced biocomposites account for about 14% of the total hemp fibre applications (lightweight pulp and paper, insulation material and biocomposites). Data for the year 2013.	

[5] http://bio-based.eu/publication-search/?wpv_post_search=Wood-Plastic+Composites+%28WPC%29+and+Natural+Fibre+Composites+%28NFC%29&wpv_filter_submit=
[6] http://bio-based.eu/publication-search/?wpv_post_search=nova-Paper+%237&wpv_filter_submit=

10	Can rubber help against the green-house effect?	Blume, A., 2015	Volumes and trends in the rubber and tyre market and that all tyre producers are working on solutions to decrease the CO_2 emissions, e. g. by reducing the rolling resistance. One important aspect in both areas, at least in the long term, will be the use of bio-based products. All alternative rubber sources are mainly seen as future options, especially if crude oil will become expensive.	

3.1.1 Key findings of the assessed studies

Mainly three groups of relevant bio-based materials were identified in the automotive sector:

1. **Biocomposites, Wood Plastic Composites (WPC) and Natural Fibre Composites (NFC)** are well established and have reached a relevant market volume in the automotive sector (150,000 t/y, see table below). The technologies have mainly been developed in the last 30 years by research in universities, institutes and in the automotive industry (OEM, Tier-one supplier and SMEs). Main drivers were price competiveness, mechanical properties and lightweight. The polymer used in these composites is mainly polypropylene (PP). Trials were made with bio-based PLA, PBS and others. But no mass production has been initiated so far.

2. **Bio-based natural and synthetic rubber for tyres and other car parts.** In 2012 more than 11 Mio tonnes natural rubber were used worldwide, and tyres are the main application of natural rubber. The highest share of natural rubber can be found in truck and winter tyres. Natural rubber is harvested mainly in the form of latex[7] from the rubber tree[8] (*Ficus elastica*[9]). Different research projects are looking for alternative rubber sources, especially Russian Dandelion (*Taraxacum koksaghyz*) and Guayule (*Parthenium argentatum*). Although large tyre producers, as for example Continental (Germany, Dandelion) and Cooper Tire (US, Guayule), have entered the field, the developments are still in a pilot stage. First high priced niche products are expected in the coming years. In addition, also, bio-based synthetic rubber can be found in some niche markets.

3. **Bio-based thermoplastics and thermosets**. There are many options to use bio-based polymers and plastics in different automotive applications. So far, only a few have been established, mainly because of cost concerns. In Europe, high performance castor oil-based polyamides are used in specific applications (for example air filter housing, acceleration pedals). In the USA soybean oil-based polyurethane foams are widely used in seat and arm rests.

[7] https://en.wikipedia.org/wiki/Latex
[8] https://en.wikipedia.org/wiki/Hevea_brasiliensis
[9] https://en.wikipedia.org/wiki/Ficus_elastica

Table 2: Production of biocomposites (WPC and NFC) in the EU in 2012 (in tonnes)
Source: Carus et al. 2015

Production of Biocomposites (WPC and NFC) in the European Union 2012 (in tonnes)

Wood-Plastic Composites	**260,000**
Decking	174,000
Automotive	60,000
Siding and Fencing	16,000
Technical Applications	5,000
Furniture	2,500
Consumer goods	2,500
Natural Fibre Composites	**92,000**
Automotive	90,000
Others	2,000
Total Volume Biocomposites (WPC and NFC)	**352,000**
Share	**15%**
Composite Production in European Union, total volume (Glass, Carbon, WPC and NFC)	2.4 Million

3.1.2 Trends and emerging markets

The analysis of studies clearly sees four main drivers for new materials in the automotive sector:

1. Costs, price competiveness
2. Lightweight construction (1 and 2 in combination: the most price competitive lightweight construction); importance can grow with electric cars.
3. Special properties
4. Environmental foot print, GHG emissions

According to the analyses, the property of being bio-based itself is no issue and has no power in marketing automobiles. Volkswagen tested this 20 years ago. Bio-based or being green has only a very small impact on selling. High performance, innovation, lightweight, low consumption is what counts in the automotive markets.

The most successful application, the press moulded natural fibres composites for interior parts such as door panels, A-B-C-columns and dashboard, fulfils criteria No. 1, 2 and 4 very well. Castor oil-based polyamides apply to criteria No. 1 and 3, the bio-based foams mainly to No. 1 and 4.

The search for alternative rubber sources is mainly driven by the wish for diversification. To depend only on one plant (rubber tree) can be dangerous in the case of diseases. Additional properties are also welcome.

The outlook for bio-based materials in the automotive sector mainly depends on the political framework. Without any supportive framework conditions, a slow increase in different sectors is expected due to improved properties and cost reduction in processing. With an increasing oil price, the development could speed up.

Additional support from policy could have a huge impact on the market penetration (see table below).

Table 3: Production of biocomposites (WPC and NFC) in the EU in 2012 and forecast 2020 (in tonnes)

Biocomposites	Production in 2012	Forecast production in 2020 (without incentives for bio-based products)	Forecast production in 2020 (with strong incentives for bio-based products)
WPC			
Construction, extrusion	190,000 t	400,000 t	450,000 t
Automotive, compression moulding & extrusion/ thermoforming	60,000 t	80,000 t	300,000 t
Technical applications, furniture and consumer goods, mainly injection moulding	10,000 t	100,000 t	> 200,000 t
Traded granulates for extrusion and injection moulding	*40,000 t*	*200,000 t*	*> 300,000 t*
NFC			
Automotive, compression moulding	90,000 t	120,000 t	350,000 t
Granulates, injection moulding	2,000 t	10,000 t	> 20,000 t

3.1.3 Discussion and identification of gaps

There are only very few reports on the bio-based materials used in the European automotive sector. There is only limited information and transparency on applications, markets and future market potential. The best investigated sector are biocomposites. But also here, the latest market data are from 2012 (some on hemp fibres for 2013) and there is no information on increase or shrinking in the last five years available.

We see mainly two reasons for this situation:

1. The automotive sector does not see itself as being part of the bio-based industries, "bio-based" is not a driver, so consequently, there are no targets to increase the bio-based share.[10]

2. The automotive sector is a very secretive group and only a few producers deliver any data on used materials, others decided not to give any data. Official statistics on bio-based shares are not available.

In total, the shares of bio-based materials in the European and USA automotive industries are almost on the same level. In Europe, we see higher shares of wood and natural fibres reinforced plastics, in the USA there are higher shares in bio-based foams (seats, armrests etc.). These products are not used in Europe because they are derived from genetically modified soy bean, cultivated for feed proteins. The soy bean oil is a by-product of the feed production. The European automotive industry will not use genetically modified biomass sources to avoid GMO discussions about their cars.

[10] Based on several interviews with experts from the German automotive industry (OEMs) in AVK – Industrievereinigung Verstärkte Kunststoffe e. V. and AVK-TV GmbH, Task Force Natural fibre-reinforced plastics, Frankfurt 2010–2017.

How to make the automotive sector feel like being a part of the bio-based industries? If the automotive sector enjoyed special advantages for using bio-based materials, this could happen. For example, the “EU End-of-Life Vehicle (ELV) Directive” and the various forms of its implementation at Member State level could create advantages: They could “include a special scheme integrating the use (of) renewable raw materials, which would automatically treat all renewable materials as a contribution to the recycling quota, independent of their concrete utilization path.” (Carus et al. 2010)

3.2 Textiles

Table 4: Studies relevant to the textile market

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	Life Cycle Assessment of man-made cellulose fibres	Shen, L., Patel, M. K., 2008	Comprehensive LCA on different bio-based fibres such as cotton, cellulose fibres and PLA fibres. Cotton is identified as the least preferred choice due to its high ecotoxicity impacts, eutrophication, water use, land use, and relatively low land use efficiencies. Cellulose fibres from Lenzing (Austria) show low environmental impacts in most categories.	
2	Nachhaltig nutzbare Potenziale für Biokraftstoffe in Nutzungskonkurrenz zur Lebens- und Futtermittelproduktion, Bioenergie sowie zur stofflichen Nutzung in Deutschland, Europa und der Welt (Final project report)	Piotrowski, S. et al., 2015	This report covers all demand sectors for bio-based industries including textile markets in 2011, 2013 and 2050. It identifies a huge worldwide supply gap for the next 30 years and a strong growth potential for cellulosic fibres. Also bio-based polymer fibres (such as PLA or PA) have an increasing potential to get relevant volumes in the textile market, whereas the production of cotton will not increase in absolute terms.	Long version with detailed information on textiles only available in German, English short version available.
3	The Fiber Year 2016 – World Survey on Textiles & Nonwovens	Engelhardt, A. W., 2016 (published annually)	The world overview on market developments in the textile sector. All kind of textile fibres are discussed by different authors with perspectives on markets, applications and innovation. Cellulose fibres show the highest growth rates in the last five years. Different new bio-based fibres are discussed.	Commercial report, but outstanding in its comprehensiveness
4	Biopolymers for textile applications	Senthilkumar, P., 2016	Technical and market overview on new options for bio-based polymer fibres in the textile sector. Many opportunities in this sector.	

3.2.1 Key findings of the assessed studies

Mainly three relevant bio-based fibre groups were identified in the textile sectors:

1. Cotton (and other natural fibres such as jute, flax, hemp, wool). From more than 50% a few decades ago the share decreased to 31% in 2015 (see figure below). The share is further decreasing, because the cotton production is stable, but the demand growth by 3-4% per year.
2. Cellulose fibres have been the winners over the last few years. Their total share in the fibres market was 6% in 2015, but with a double-digit growth, they show the fastest increase of all textile fibres (see both figures below).
3. Bio-based polymer fibres such as PLA, PDO or castor oil-based polyamides can so far only be found with small shares in specific applications, mainly home textiles and hygienic products.

Additional bio-based fibres are under development or introduced in small niche markets: Alginate fibres, chitin and chitosan fibres, soybean protein fibres, non-food milk casein fibres, spider silk and more.

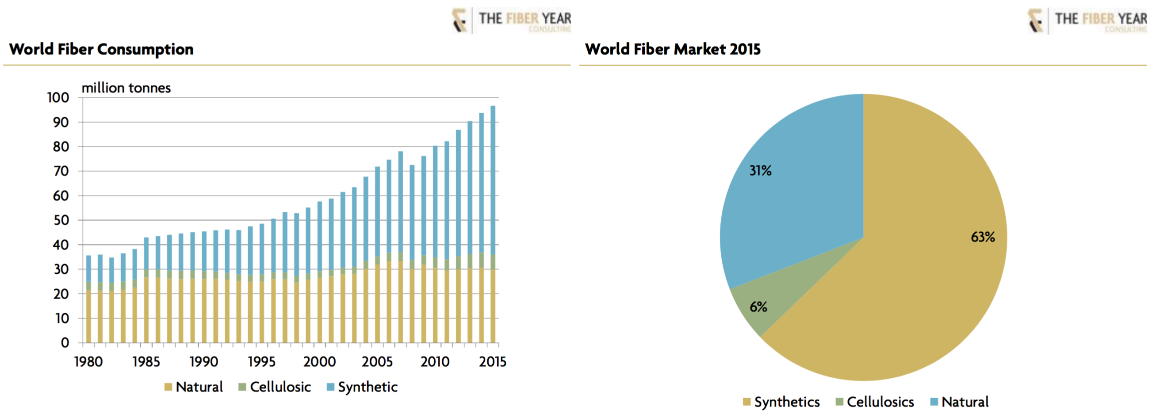


Figure 1: World Fiber Consumption and market 2015.
Source: The Fiber Year 2016

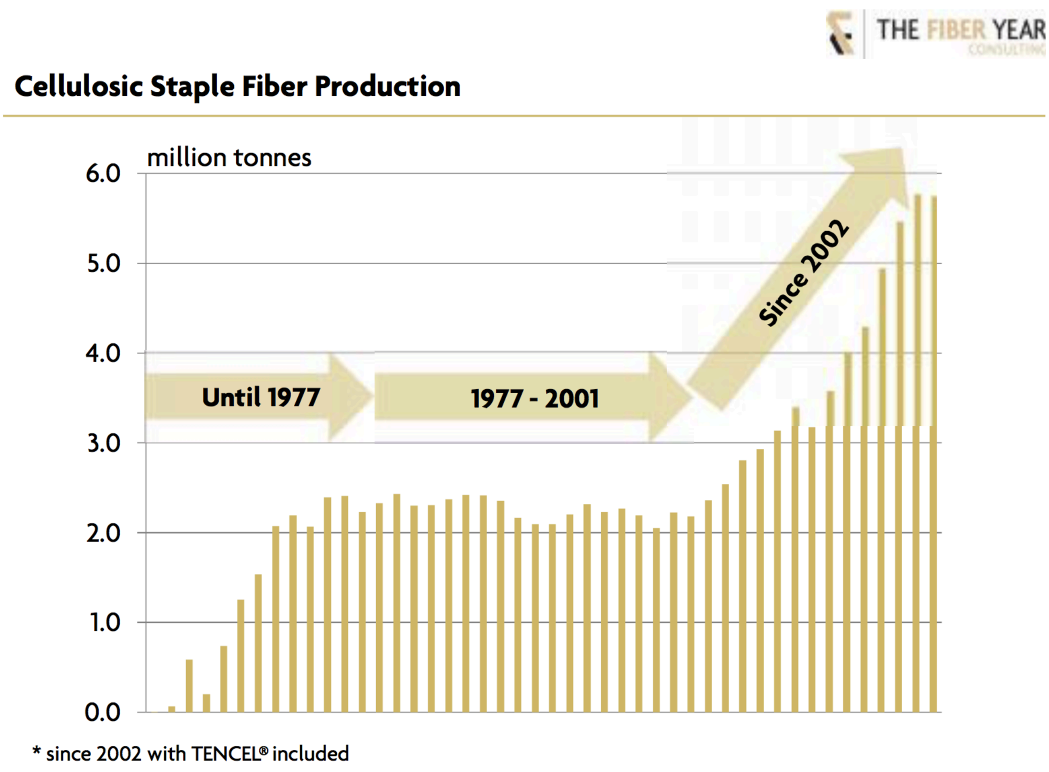


Figure 2: Development of cellulosic fibre production
Source: The Fiber Year 2016

3.2.2 Trends and emerging markets

The textile sector does not see itself as part of the bio-based industries, although about 37% of textile fibres are in fact bio-based – a higher bio-based share than in most other market sectors.

The main driver in the textile sector is the fast-growing demand for products and how to cover this demand. The figure below shows a textile fibre gap of about 150 Million tonnes until the year 2050.

A relevant increase of the cotton production is not expected because of limited cultivation areas and infrastructure as well as the high environmental footprint of the cotton production. Other natural fibres have only very small cultivation area and very limited processing plants. Also, modern technical equipment for these fibres is not available. Instead, they often rely on traditional harvesting and processing by hand, which is very labour intensive and often connected to negative environmental impacts (e.g. through water retting).

If the textile fibre gap is not to be filled by petrochemical fibres only, **huge investment in cellulose fibres and bio-based polymer fibres is needed**. It should be noted that textile consumers are not aware of the term “bio-based”, but are highly interested in “natural” textiles. Natural fibres are often preferred in comparison to petrochemical fibres.

Natural fibres have a history of being considered the highest quality fibres, valued for their comfort, soft hand and versatility. Natural fibre textiles absorb perspiration and release it into the air, a process called “wicking” that creates natural ventilation. This “breathability”

of natural fiber textiles makes their wearers less prone to skin rashes, itching and allergies. But today, these prejudices against synthetic fibres cannot anymore be backed up by facts. Only for the cheapest synthetic fibres, this is still true. High performance synthetic fibres – petrochemical as well as bio-based – used in functional and sport clothing can absorb perspiration and release it into the air even better than cotton fibres. Allergy sufferers need to avoid natural fibres as often as synthetic fibres. Nevertheless, consumers often prefer natural fibres.

Cellulose fibres, especially Viscose, have been produced since the 19th century, but the concept of bio-based industries has existed only for about a decade. A classification of all kinds of cellulose fibres to be "second generation" is therefore questionable. However, with the technological progress of the last decades, the production of cellulose fibres is not only much more environmentally friendly than in the past, but can also be fully integrated in second generation lignocellulosic biorefineries, producing fibres, chemicals, fuel as well as food/feed additives. Wood-based fully integrated biorefineries are a big opportunity to produce cellulose textile fibre on high volume. The biggest investment in this area in the last few years has been Metsä fibre in Finland.

Additional demand for bio-based and biodegradable textiles can arise from the increasing microplastic problem. Washing machines release thousands of small fibres per washing process. If those fibres are not biodegradable, they accumulate in the environment and finally in the ocean and fish. Cotton and cellulose fibres as well as some biopolymer fibres biodegrade in fresh water and more slowly also in the ocean.

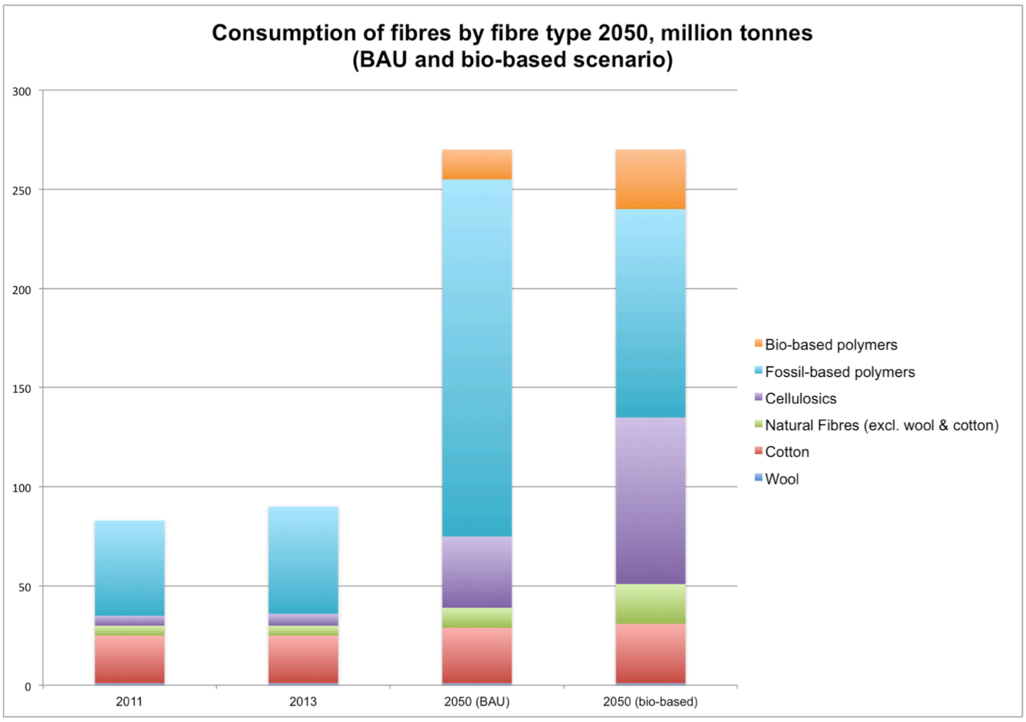


Figure 3: Consumption of fibres by fibre type 2050, million tonnes (BAU and bio-based scenario).
Source: Piotrowski 2015

3.2.3 Discussion and identification of gaps

The discussions around bio-based industries have mostly ignored the huge market for textile fibres. Bio-based policies can even be a hurdle for bio-based textile fibres: Second generation biofuels are strongly supported by Brussels and the member states – in contrast to "second generation" textile fibres, which bring higher value added and more jobs compared to biofuels but are made from the same lignocellulosic raw material.

Based on our research, experts from nova-Institute maintain that Europe would need an own textile fibre strategy. Which raw materials should be used for textiles in the future? Petrochemical fibres or cotton? New bio-based polymer fibres? Or cellulose fibres from European forests produced in advanced wood-based biorefineries? Indian investments in the Swedish cellulose fibre production of Birla prove that there are big opportunities for this sector in Europe.

Research and development should focus on efficient and environmentally friendly processes to produce cellulose fibres. This could also be a solution to offset problems arising for the pulp and paper sectors arising from the decreasing demand for pulp and paper in traditional sectors such as printed newspapers and books.

3.3 Medical, healthcare and pharmaceuticals

Table 5: Studies relevant to the medical, healthcare and pharmaceutical sector

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	Assessment of Bio-Based Pharmaceuticals The Cephalexin Case	Bruggink, A. and Peter Nossin, P., 2006	The paper describes the various ways biotechnology, especially metabolic engineering approaches, influences pharmaceuticals and gives a historic and technological overview of the various possibilities and roles bio-based products have. Renewable resource-based biotechnologies are having a threefold impact on pharmaceuticals: 1) Molecular biology, including genomics, proteomics, metabolic pathway engineering etc., is are a rich source for new cell-based medicines, i.e. biopharmaceuticals. Although renewable-based, the real motive for this development is new drugs rather than rational resource employment. 2) The same and similar techniques are used to improve existing or develop new fermentation processes (biosyntheses) for enzymes and existing (mainly nature-based) products. 3) To a large extent, these enzymes are used to replace stoichiometric, non-catalytic chemistry.	Out of scope timewise, but particularly interesting study as it also contains LCA data, comparing conventional Cephalexin production with biotechnological production. http://onlinelibrary.wiley.com/doi/10.1002/0470022442.ch19/summary
2	The Emerging Biobased Economy - A multi-client study assessing the opportunities and potential of the emerging biobased economy	Informa Economic, 2006	Comprehensive report on technology, trends, markets and history of bio-based molecules and their role in the pharmaceutical sector. The global market for pharmaceuticals was estimated to be approximately $466 billion in 2003. 187 biopharmaceutical products accounted for approximately 12% of global sales. 2005, the biopharmaceutical market was estimated at $70.8 billion. By 2010 biopharmaceutical products are expected to represent 17% of total pharmaceutical sales.188 The global market for antibiotics is approximately $25-30 billion. 189,190 Cephalosporins dominate with 26.3% of the market; however, quinolones and fluoroquinolones were expected to gain market share on cephalosporins in the near future.	Comparably old article but still detailed description of various important bio-based molecules and their role in the pharmaceutical sector. www.auri.org/assets/2012/08/Biobased-Study-Informa.pdf

3	Opportunities in the Emerging Bioeconomy	Golden, J. and Handfield, R. 2014	This paper describes and evaluates the whole spectrum of bio-based products. It also confirms nova's evaluation that the pharmaceutical market is very complex because of the multitude of possible production processes and formulation options. Describing the biopharmaceuticals market, the paper notes that biotech products, such as bioengineered vaccines and biologics, comprised 21 % of the worldwide market for prescription and over the counter product sales in 2012, and, by 2018, they were projected to account for 25 % of this $858B sector. Also, 51 % of the sales of the top 100 products in 2018 were projected be bio-based.	https://www.biopreferred.gov/files/WhyBiobased.pdf
4	The Junction of Health, Environment and the Bioeconomy	Damianova, Z. et al., 2015	The report identifies trends at the junction of health, environment and the bioeconomy and outlines the necessity of a systemic approach to challenges, often going beyond the three areas, for example to encompass issues of energy and mobility. The paper mentions, for instance, that the challenge is to make the Green Economy work in practice, which requires placing the right values on environment and health outcomes in actual policy and economic decisions. The value of a healthy environment is still largely invisible in national accounting practices. Achieving healthy environmental and socio-economic conditions will require concerted effort from all parts of the world and will provide important innovation opportunities. Observing the intersection between health, environment and the bioeconomy gives the opportunity to identify and exploit the synergies that facilitate the emergence of 'triple wins' (i.e. research delivering benefits across the three fields) as behaviours, knowledge and technologies advance. It offers a unique occasion to ensure a safer and more sustainable society through the development of a green, circular economy.	EU Commission Report http://bookshop.europa.eu/en/the-junction-of-health-environment-and-the-bioeconomy-pbKI0514154/
5	BUILDING THE BIOECONOMY. Examining National Biotechnology Industry Development Strategies Globally	Pugatch Consilium, 2015	This publication examines and identifies policies and best practices that pave the way for creating an environment and ecosystem that enables biotech innovation which concentrates on bio-pharmaceuticals and industrial biotechnology. The key outcomes are that one size does not fit all – different biotech sectors have different policy needs. The individual significance of related policies for each biotechnology sector, such as in the fields of biopharmaceutical, green and industrial biotechnology, may vary, at times significantly, depending on the specific needs of that particular sector.	http://www.pugatch-consilium.com/reports/BIO%202016%20report_US%20size_SP.pdf.

6	High-value low-volume bioproducts coupled to bioenergies with potential to enhance business development of sustainable biorefineries	Budzianowski, W., 2016	The article describes the market size and volume for several bio-based products in the context of additional valorisation in biorefinery concepts. It mentions that the global market for biopharmaceuticals is projected to rise to about 11 % each year. About 50–60 % of today's pharmaceutical drugs are either of natural origin, or they are obtained through the use of natural products as a raw material for chemical synthesis. At least 120 commercial drugs are prepared from higher plants, and 10–25 % of prescribed drugs today contain at least one active compound isolated from higher plants. Therefore, markets for biopharmaceuticals accept biomass derived drugs and with support of technological progress biorefineries may contribute to drug markets in a meaningful way.	http://www.sciencedirect.com/science/article/pii/S1364032116310425
7	EBE White Paper on Personalised Medicine	European Biopharmaceutical Enterprise, 2016	The White Paper describes the challenges in delivering personalised medicine, from the classification of diseases, the need for greater investment in e-health and big data infrastructure, to calls for effective regulatory science and access mechanisms for the benefit of patients. The key messages of the paper are related to a health technology assessment which suggests to realise the true value of personalised medicine, the benefit to patient care both in terms of clinical and economic value to health systems must be consistently factored into pricing and reimbursement decisions, using robust methodology that is consistent across the EU. Timely and co-ordinated advice from regulators and payers should be easily available to companies.	EBE http://www.ebe-biopharma.eu/newsroom/76/59/EBE-releases-White-Paper-on-Personalised-Medicine-with-a-focus-on-key-challenges
8	World Preview 2016, Outlook to 2022	Evaluate Pharma, 2016	Most up-to-date report we could find on the whole pharmaceutical market. Talking about the share of bio-based products, the report describes that the use of biotechnology continues to rise, contributing to 50 % of the Top 100 product sales by 2022. The uptake of biologics is expected to continue as novel biologic blockbusters keep entering the pharmaceutical market. The penetration of biotech products is set to increase from a 24 % market share in 2015 to 29 % in 2022. In 2022, 50 % of the value of the top 100 products will come from biologics as established chemical products drop off the patent cliff and new breakthrough biologics get approved. Within this outlook, Roche will continue to be the undisputed market leader and is expected to further consolidate its position with the launch of novel biologic therapies (Tecentriq and Ocrevus, but also emicizumab and lampalizumab).	http://www.evaluate-group.com/public/reports/EvaluatePharma-World-Preview-2016.aspx

9	Biomedical Applications of Biodegradable Polyesters	Manavitehrani, I. et al., 2016	This papers focuses on the emerging (compared to the whole pharmaceutical sector) market of tissue engineering/regenerative medicine and states the importance bio-based biodegradable (the focus of this paper is PLA and PHB) molecules can play here. They found that the current market for regenerative implantation surgeries, therapeutic cell culturing and tissue repair is approximately US $23 billion, and it is anticipated to reach US $94.2 billion by the end of 2025. It also correlates the other polymer properties to their medical applications. E.g. PLA's intrinsic high mechanical strength (56.96 MPa compression and 3500 MPa tensile modulus) can lend it to applications in surgical screws and other internal fixation devices. Application tests in humans have shown that non-modified PLA is best suited for non-load bearing applications. Nonetheless, research on modifying PLA will make more load-bearing applications (e.g. artificial joints) possible.	

3.3.1 Key findings of the assessed studies

Reviewing the literature on bio-based pharmaceuticals or their components proved to be only partially fruitful. No studies seem to exist which concern themselves with the notion of a bio-based share – in terms of feedstock – in neither the pharmaceuticals market itself nor the excipients market. The focus in the pharma sector lies on the biotechnological processes. These, in turn, use bio-based feedstock.
In the API (= active pharmaceutical ingredient) segment of the pharma-market, this is caused by the fact that different jargon (biosimilars, biopharmaceuticals, biologics) is used for products such as penicillin, which is produced using fungi. This example also shows that producers might not consider their products to be bio-based because they have such a long tradition of being produced that way. In some cases, extraction from flowers or production with microorganisms is even the only way to produce certain drugs. Therefore, we included papers with information on the biopharmaceutical market.
As **Fehler! Verweisquelle konnte nicht gefunden werden.** and Figure 4 demonstrate, the excipients market is incredibly complex because of e.g. the different formulations the same type of pill can have. This is probably the reason, why no review tackled the daunting task of evaluating the bio-based share of the numerous chemicals which can be used in the formulations, which could be theoretically be produced from biomass feedstock.

Table 6: Example of the different segments of the excipients market
Source: http://www.marketsandmarkets.com/Market-Reports/pharma-excipients-market-956.html

Inorganic Chemicals	Organic Chemicals
- Calcium Phosphates - Calcium Carbonate - Calcium Sulfate - Magnesium Stearate - Halites - Metallic Oxides - Others	Carbohydrate - Actual Sugars -Lactose -Sucrose -Maltose -Dextrose - Sugar Alcohol -Sorbitol -Mannitol -Xylitol -Other Sugar Alcohols - Artificial Sweeteners - Starch -Modified Starch -Dried Starch -Converted Starch - Cellulose -Cellulose Ethers -Microcrystalline Cellulose -Cellulose Esters -CMC and Croscarmellose Sodium Petrochemicals - Glycols -Polyethylene Glycols -Propylene Glycols - Povidones - Mineral Hydrocarbons -Petrolatum

	-Mineral waxes -Mineral Oils - Acrylic Polymers - Other Petrochemical Excipients Oleochemicals - Fatty Acids - Mineral Stearate - Glycerine - Other Oleochemicals Excipients Proteins Others

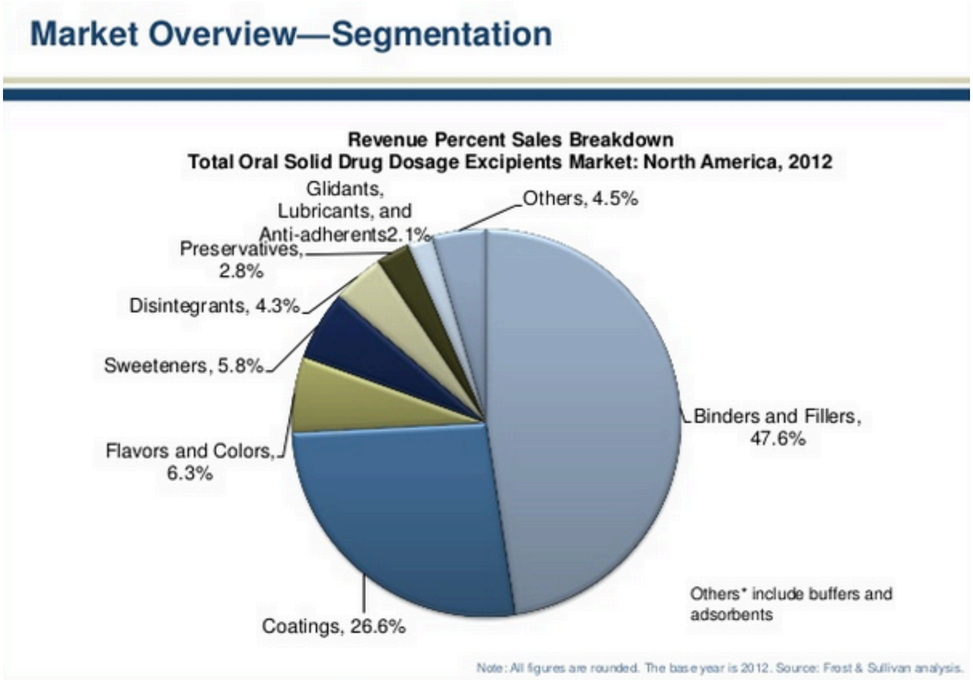


Figure 4: Example of the different segments of the excipients market; based on the revenue percent sales breakdown for an oral solid drug formulation.
Source: www.slideshare.net/FrostandSullivan/analysis-of-the-oral-solid-drug-dosage-excipients-market

In the section on the “The global role of health, pharma and biotechnology in the bioeconomy”, we chose to describe the bioeconomy, biotechnology and the role of the medical/pharmaceutical sector using a wider definition of the word “biotechnology”. Instead of equalling “biotechnology” with the description “produced using fermentation”, broader applications where biotechnological techniques play a role such as the deep sequencing needed for personalized medicine are included in the first section of this report.
The focus of the third section of the analysis will be highlighting papers that concern themselves with future applications and emerging markets for bio-based solutions to health issues.

The global role of health, pharma and biotechnology in the bioeconomy

The study of Damianova et al., 2015 describes the intersectionality and synergies between health, environment and the bioeconomy. Using these can lead to new avenues in the prevention and treatment of diseases in a holistic health approach, by applying omics – technologies used in biotechnology – to broader applications such as nutrient use and disease prevention by monitoring and detecting disease-markers, together with Information and Communication Technologies (ICTs). The great complexity of issues at the junction of health, environment and the bioeconomy also points to the need for very large scale collaborative research if European innovators were to achieve global leadership and if real transformational change towards sustainability should be achieved. This implies a need to make space in programmes for a significant part of the budget to be allocated to major collaborative initiatives on a much larger scale than the norm of Horizon 2020 (e.g. € 20-30 million). The importance of bringing together new stakeholders to work on interdisciplinary projects is also stressed in the other papers.

To use good basic science in Europe to avoid migration of business ventures outside of Europe, the European Biopharmaceutical Enterprises (2016) suggests in a position paper to improve the current gap in translating innovation into businesses. The recommended key actions are improving technology transfer/business acumen of innovators, specific actions within the European funding ecosystem to improve investment within Europe and speeding up development of a single capital market for biotech companies. These measures could be supplemented by identification and Europe-wide implementation of best supportive incentives such as tax credits for research and IP commercialization agreements with investors in biotech companies.

The Pugatch Consilium (2016) analysed different national policies on how efficient they were in producing the most biotech-output. Below an excerpt of the compared countries and how they fared on biotech performance measurements:

Measuring Policy Inputs and Biotech Outputs: The Biotech Policy Performance Measure (cont.)

Policy Inputs	Malaysia	Israel	Japan	Singapore	Korea	Switzerland	UK	US
Human capital	Mixed	Attractive	Attractive	Attractive	Attractive	Attractive	Mixed	Mixed
Infrastructure for R&D	Mixed	Attractive	Attractive	Mixed	Attractive	Attractive	Mixed	Attractive
Intellectual property protection	Mixed	Mixed	Attractive	Attractive	Attractive	Attractive	Attractive	Attractive
The regulatory environment	Mixed	Mixed	Attractive	Attractive	Attractive	Mixed	Attractive	Attractive
Technology transfer frameworks	Challenging	Attractive	Attractive	Attractive	Attractive	Attractive	Attractive	Attractive
Market and commercial incentives	Challenging	Mixed	Mixed	Mixed	Challenging	Mixed	Mixed	Attractive
R&D tax incentives	Attractive	Attractive	Mixed	Mixed	Mixed	Mixed	Attractive	Mixed
Legal certainty (including the rule of law)	Mixed	Not available	Attractive	Attractive	Attractive	Not available	Attractive	Mixed
Biotech Outputs								
Scientific publications by population	Struggling to compete	Highly competitive	Mixed	Mixed	Mixed	Highly competitive	Highly competitive	Highly competitive
Quality of academic publications	Not available	Highly competitive	Mixed	Not available	Mixed	Highly competitive	Highly competitive	Highly competitive
Clinical trials per capita	Mixed	Highly competitive	Mixed	Highly competitive	Mixed	Highly competitive	Highly competitive	Highly competitive
Clinical trials for biologics, 2010-2015, per capita	Mixed	Highly competitive	Mixed	Highly competitive	Mixed	Highly competitive	Highly competitive	Highly competitive
Early phase (Phase I and II) Clinical trials for biologics, % of total CTs, 2010-2015	Struggling to compete	Mixed	Mixed	Mixed	Highly competitive	Mixed	Highly competitive	Highly competitive
Biotechnology triadic patenting, share of global total average 1999-2012	Struggling to compete	Mixed	Highly competitive	Mixed	Highly competitive	Highly competitive	Highly competitive	Highly competitive
Biopharma product launches, % available in country within 5 years of global product launch, 1983-2000	Struggling to compete	Struggling to compete	Mixed	Mixed	Highly competitive	Highly competitive	Highly competitive	Highly competitive
National % share total number of patents from top 50 PCT applicants: universities, 2014	Struggling to compete	Mixed	Highly competitive	Mixed	Highly competitive	Mixed	Mixed	Highly competitive
Biotechnology crops, hectares under cultivation, % of total 2015	Struggling to compete	Struggling to compete	Struggling to compete	Struggling to compete	Struggling to compete	Struggling to compete	Struggling to compete	Highly competitive
Biopharmaceutical Competitiveness Index (BCI) Survey, 2015 Ranking	Not available	Mixed	Mixed	Highly competitive	Highly competitive	Highly competitive	Highly competitive	Highly competitive
Venture Capital & Private Equity Country Attractiveness Index, Economy Ranking	Mixed	Mixed	Highly competitive	Highly competitive	Mixed	Highly competitive	Highly competitive	Highly competitive

Figure 5: Comparison of various policy inputs and their effect on biotech output in various countries.
Source: Pugatch, 2016

The role of bio-based products in the pharmaceutical sector

As the following figures indicate, apart from the API, numerous molecules can be used as excipients to formulate the complete pill/medicine. Probably, due to the great diversity in delivery mode, functionality and chemical group which can be used to create the finished pill, writing a comprehensive market analysis of how many APIs and excipients are bio-based and deriving from these numerous analyses a complete picture of the bio-based share

in the API and excipients part alone is cumbersome. Similar to the traditional share of oleochemical molecules in the personal/homecare market where their manufacturers never considered themselves part of the bioeconomy/bio-based chemicals markets, some APIs have a long tradition of being manufactured via microorganisms e.g. several antibiotics have always been manufactured using fungi. A second wave of APIs produced using fermentation came in the 60s/70s when insulin and human growth protein were manufactured using genetically modified microorganisms like *E. Coli*. Here the terminology used was not bio-based but "recombinant", meaning created through changing the DNA. This is another example for the industry's focus on the technology used to create their products, instead of the feedstock. Lately, the jargon used in the pharmaceutical industry for these products is "biologics, biopharmaceuticals, biosimilars". These terms, on the one hand, signify their microbial origin but partially also mean that patented molecules are recreated with minor changes in their molecular structure which does not alter their pharmacological effect. This will become particularly important in the upcoming years which have been described as approaching a patent cliff. This means that the patents for several blockbuster drugs will run out until 2019 (Informa, 2006). This will boost the biosimilar market and will therefore probably also push the bio-based share in the whole pharmaceuticals market.

Table 7: Products obtained by microbial fermentation.
Source: Informa, 2006

Pharmaceuticals	Amino acids and other organic acids	Enzymes	Solvents
- Antibiotics - Stereoids - Human proteins - Vaccines - Vitamins	- Lysine - Glutamic acid - Gluconic acid - Citric acid - Itaconic acid - Gibberellic acid - Lactic acid	- Proteases - Amylases - Cellulases	

Drug	Clinical action or use	Primary botanical origin
Atropine	Anticholinergic	Atropa belladonna
Caffeine	CNS stimulant	Camellia sinensis
Camphor	Rubefacient	Cinamomum camphora
Chymopapain	Chemonucleolysis	Carica papaya
Cocaine	Local anaesthetic	Erythroxylum coca
Codeine	Analgesic/anti-tussive	Papaver somniferum
Colchicine	Anti-gout	Colchicum autumnale
Digitoxin	Cardiotonic	Digitalis purpurea
Digoxin	Cardiotonic	Digitalis lanata
Emetine	Amoebicide	Cephaelis ipecacuanha
Ephedrine	Sympathomimetic	Ephedra sinica
Galanthamine	Cholinesterase inhibitor	Lycoris squamigera
Gossypol	Male contraceptive	Gossipium spp.
Hyoscamine	Anticholinergic	Hyoscamus niger
Kawain	Tranquiliser	Piper methysticum
Levodopa	Anti-Parkinsonian	Mucuna deeringiana
Menthol	Rubefacient	Mentha spp.
Methoxsalen	Psoriasis/vitiligo	Ammi majus
Methyl salicylate	Rubefacient	Gaultheria procumbens
Morphine	Analgesic	Papaver somniferum
Nordihydroguaiaretic acid	Antioxidant	Larrea divaricata
Noscapine	Anti-tussive	Papaver somniferum
Ouabain	Cardiotonic	Strophanthus fratus
Physostigmine	Cholinesterase inhibitor	Physostigma venenosum
Pilocarpine	Parasympathomimetic	Pilocarpus jaborandi
Podophyllotoxin	Topical treatment for condylomata acuminata	Podophyllum peltatum
Quinidine	Anti-arrhythmic	Cinchona ledgeriana
Quinine	Anti-malarial	Cinchona ledgeriana
Reserpine	Antihypertensive	Rauwolfia serpentina
Scopolamine	Sedative	Datura metel
Sennosides A and B	Laxative	Cassia spp.
Tetrahydrocannabinol	Antiemetic	Cannabis sativa
Theophylline	Bronchodilator	Camellia sinensis
Tubocurarine	Muscle relaxant	Chondodendron tomentosum
Vinblastine	Anticancer	Catharanthus roseus
Vincristine	Anticancer	Catharanthus roseus
Yohimbine	Aphrodisiac	Pausinystalia yohimbe

Figure 6: Classic plant drugs extracted from plants.
Source: Informa, 2006

The nova expertise on the high fragmentation of the pharmaceuticals market is confirmed by the following from Informa (2006):

> "The drugs with botanical origins, which are available today, can be divided into a number of categories. These include long-known products, which still remain the drug of choice today, such as the cardiotonic digitoxin, and newer drugs, such as the taxoids from *Taxus spp*. And artemisinin, and its derivatives from Artemisia spp. There is growing demand for natural-based medicines; therefore, these medicines will take an increasing proportion of the existing (largely synthetic) drug markets."

The same source gives an overview of the pharmaceutical industry:

> "The demand for new pharmaceutical, nutraceutical and industrial products is being driven by fundamental shifts in demand for improved health and quality of life and renewed concern about the long-term availability of petroleum-based products that replaced bio-based materials in the last century. In 2000, 25% of the active components of pre-

scribed pharmaceuticals had their origin in flowering plants and this was expected to increase to 30% over the next decade. This was a $30 billion global market, growing at 6% per year in 2000. Herbal supplements, minerals and vitamins, were a $45 billion global market in 2000, and were expected to continue to experience growth of 10% or more in many segments. To this market add cosmeceuticals, growing at 8% and with sound prospects for sustained development. Products for the cardiovascular market stood at $30 billion/year, with potential to be supplied by plants such as *Digitalis spp., Strophanthus fratus, Cinchona spp. and Rauwolfia serpentina. Ginkgo biloba*, ginseng, garlic and Echinacea are likely to continue to experience strong growth in demand in Europe and the USA."

Product	**Market Size** (US$ million)
Erythropoietin	6803
Blood clotting factors	2585
Interleukin	184
Insulin	4017
Inteferon	3919
Monoclonal antibody (cancer)	1751
Monoclonal antibody (various)	1152
Growth hormone	1706
Growth factor	115

Figure 7: Current biologics and market size.
Source: Informa, 2006

Company	**Crop**	**Pharmaceutical**
Ventria Bioscience	Rice	Lactoferrin, lysozyme
Chlorogen, Inc.	Tobacco	Cholera vaccine, human serum albumin, interferon
Medicago	Alfalfa	Hemoglobin
Meristem	Corn, tobacco, alfalfa	Hemoglobin, gastric lipase, albumin, cancer therapeutic antibodies
EpiCyte	Corn	Monoclonal antibodies
SemBio Systems	Safflower	Antiobesit peptid, somatotropin
MPB Cologne	Potato, rapeseed	Antibodies for the detection of food/water borne pathogens
AttaGen	Potato	Hemoglobin, factor VIII, human growth hormone
Large Scale Biology Corp.	Tobacco	Alpha galactosidase A, patient specific cancer vaccines, B-cell non-Hodgkin's Lymphoma

Figure 8: Technologies under development for plant-based pharmaceuticals
Source: Informa, 2006

Compound	Production Method			Applications
	Biotechnology	Chemical	Extraction	
Ascorbic Acid (C)	+[a]			Feed, food, pharmaceutical
Thiamin (B_1)		+		Food, pharmaceutical
Riboflavin (B_2)	+			Feed, pharmaceutical
Biotin	+[b]	+		
Pantothenic acid	+[a]	+		Feed, food, pharmaceutical
Pyridoxine (B_6)		+		Feed, food, pharmaceutical
Vitamin D_3		+	+	Feed, food
Vitamin A		+		Feed, food, pharmaceutical
α-Tocopherol (E)	+[b]	+	+	Feed, food, pharmaceutical, nutraceutical

[a] Combination of microbial and chemical reactions
[b] Pilot scale process

Figure 9: Industrial production of vitamins.
Source: Informa, 2006

	2000	2001	2002	2003	2004	2005*	2006*	2007*	2008*
Ethical	317.1	363.4	401.0	437.6	477.4	520.9	568.3	620.0	677.8
Generics	24.0	27.0	30.5	37.0	41.3	46.1	51.4	57.4	64.0
OTC	70.5	73.8	78.5	82.0	85.5	89.2	93.0	97.0	101.0
Biopharm aceuticals	22.1	26.3	31.0	36.5	40.1	44.1	48.4	53.2	58.6
Total World Market	433.7	490.5	541.0	593.1	644.4	700.2	761.2	827.7	901.4

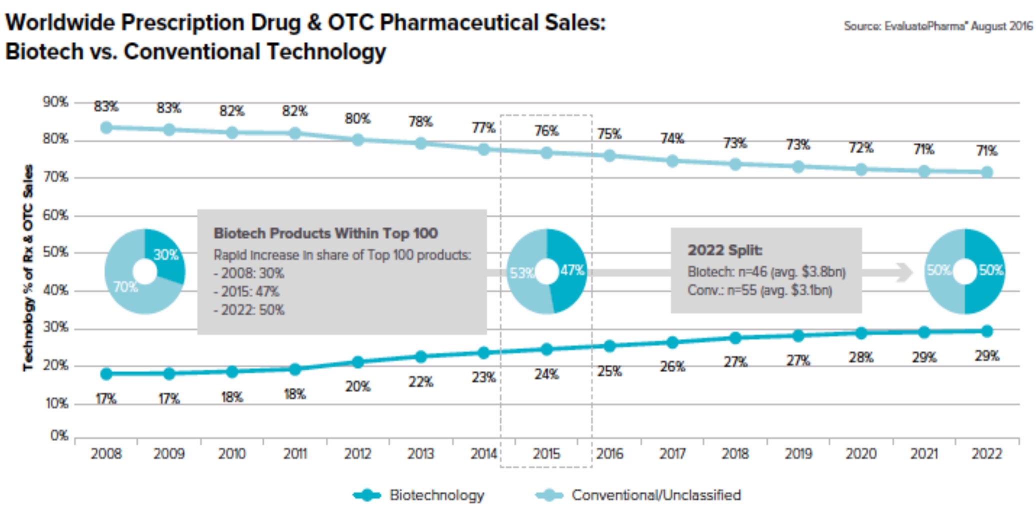
* Forecast Estimate

Ethical pharmaceuticals account for 74% of the market. Ethical pharmaceuticals are only available by prescription and are name brand as opposed to generic. This sector is under increasing pressure from generics and biopharmaceuticals.

Figure 10: Woldwide pharmaceutical market with predictions starting from 2005 ($ Billions).
Source: Informa, 2006

The Informa predictions on the pharmaceutical market are confirmed by a study from Budzianowski (2016). In addition, this paper also draws the connection to using the remaining plant material after API-extraction in biorefinery concepts. The global market for biopharmaceuticals is projected to rise by about 11% each year. About 50–60 % of today's pharmaceutical drugs are either of natural origin, or they are obtained through the use of natural products as a raw material for chemical synthesis. At least 120 commercial drugs are prepared from higher plants, and 10– 25 % of prescribed drugs today contain at least one active compound isolated from higher plants. Therefore, markets for biopharmaceuticals accept biomass derived drugs and with support of technological progress biorefineries may contribute to drug markets in a meaningful way. Similar characteristics are associated with markets for biocosmetics and bionutrients which all are already well penetrated by bioproducts. Budzianowski (2016) names examples such as hemoglobin obtained from corn, human growth hormone (potato), alpha galactosidase (tobacco), cholera vaccine (tobacco), gastric

lipase (corn), and lactoferrin (rice). Selling prices reach 100–200 €/kg and the resulting biomass is suitable for processing to bioenergy within biorefineries. Biopharmaceuticals can also be obtained by extraction from microbial biomass. Examples include shikimic acid and quinic acid. Shikimic acid is a precursor of anti-viral drugs, especially related to influenza. It is currently obtained from the fruit of Illicium plants in an energy and material intensive multi-step process. Therefore, its large scale production by fermentation in biorefineries followed by extraction from microbial biomass attracts attention.
Golden and Handfield (2014) also corroborate the importance of biomass-derived products for the pharmaceutical sector. They state that biotech products, such as bioengineered vaccines and biologics, comprised 21 % of the worldwide market for prescription and over the counter product sales in 2012. They even go so far as to claim that 51 % of the sales of the top 100 products in 2018 will be bio-based.
A study of EvaluatePharma (2016) gives the most recent results as indicated with the graphs below. Use of biotechnology in the pharma sector continues to rise, contributing to 50% of the Top 100 product sales by 2022. Roche is the current market leader. The uptake of biologics is expected to continue as novel biologic blockbusters keep entering the pharmaceutical market. The penetration of biotech products is set to increase from a 24% market share in 2015 to 29 % in 2022. In 2022 50 % of the value of the top 100 products will come from biologics as established chemical products drop off the patent cliff and new breakthrough biologics get approved. Roche will continue to be the undisputed market leader and is expected to further consolidate its position with the launch of novel biologic therapies. Bristol Myers Squibb is expected to climb the ranking provided Opdivo mantains the current expectations. Amgen is set to fall down the rankings due to a number of its biologics going off patent, but new launches are expected to still ensure a positive CAGR (+3 %) through 2022.
A current ranking on the top producers of biotechnologically produced pharmaceuticals is also given in the table below.



Worldwide Prescription Drug & OTC Sales by Technology (2008-2022)

Source: EvaluatePharma® August 2016

Technology	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Biotechnology	17%	17%	18%	18%	20%	22%	23%	24%	25%	26%	27%	27%	28%	29%	29%
Conventional/Unclassified	83%	83%	82%	82%	80%	78%	77%	76%	75%	74%	73%	73%	72%	71%	71%
Total Prescription & OTC Sales	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

	WW Sales ($bn)														
Technology	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Biotechnology	117	119	128	141	152	165	178	184	200	220	242	266	290	315	337
Conventional	423	433	442	463	440	431	442	433	440	453	473	497	526	556	582
Other Unclassified Sales	151	145	151	162	161	166	168	159	171	185	196	207	220	232	245
Total Prescription & OTC Sales	**691**	**697**	**720**	**766**	**754**	**762**	**788**	**776**	**812**	**858**	**911**	**970**	**1037**	**1102**	**1164**

Figure 11: Global pharmaceutical sales
Source: EvaluatePharma, 2016

		WW Sales ($bn)			WW Market Share			
Rank	Company	2015	2022	% CAGR 15-22	2015	2022	Chg. (+/-)	Rank Chg.
1.	**Roche**	31.1	**43.6**	+5%	16.9%	12.9%	-4.0pp	+0
2.	**Sanofi**	14.9	**25.3**	+8%	8.1%	7.5%	-0.6pp	+2
3.	**Novo Nordisk**	15.1	**24.4**	+7%	8.2%	7.2%	-1.0pp	+0
4.	**Amgen**	18.8	**23.2**	+3%	10.2%	6.9%	-3.3pp	-2
5.	**Bristol-Myers Squibb**	4.5	**18.2**	+22%	2.5%	5.4%	+2.9pp	+6
6.	**Johnson & Johnson**	10.9	**17.7**	+7%	5.9%	5.2%	-0.7pp	+1
7.	**AbbVie**	14.8	**15.5**	+1%	8.0%	4.6%	-3.4pp	-2
8.	**Eli Lilly**	6.6	**15.4**	+13%	3.6%	4.6%	+1.0pp	+1
9.	**Pfizer**	11.9	**14.8**	+3%	6.5%	4.4%	-2.1pp	-3
10.	**Merck & Co**	7.9	**13.0**	+7%	4.3%	3.9%	-0.4pp	-2

Figure 12: Top 10 companies and worldwide prescription drug sales from biotechnology in 2015 and predictions for 2022.
Source: EvaluatePharma, 2016

3.3.2 Trends and emerging markets

Especially the excipients sector has the potential for a greater share of bio-based alternatives. For example, their additional functionalities such as biodegradability, non-toxicity and biocompatibility make them ideal candidates for tissue engineering (e.g. using a PHA-scaffolding to use the patient's own cells to reconstruct parts of his oesophagus in the lab to be

transplanted to the patient) and drug-delivery especially combining the bio-based polymers with nanoparticles (where options also exist to manufacture them using fermentation) can increase the bioavailability of compounds, which e.g. dissolve only partially in watery media. Enabling certain drugs to cross the blood brain barrier will open up additional applications and markets.
Table 8 shows the application of some bio-based polymers in the medical sector. Manavitehrani (2016) describes the current market for regenerative implantation surgeries, therapeutic cell culturing and tissue repair is approximately US $23 billion. It is projected to reach US $94.2 billion by the end of 2025.
Once research has advanced to make culturing whole organs in a petridish on a regular basis in hospitals, the market should grow further, because these 3D-cultures will require biocompatible and –degradable scaffolds to grow the cells on. Another trend should be, according to nova expertise, that petro-based and even plant-extraction-based APIs will be produced via fermentation, e.g. using yeast cells to produce the plant-flavonoid resveratrol.

Table 8: Commercial products made from biodegradable polyesters and their applications.
Source (adapted from): Manavitehrani, 2016

Polymer	Applications	Commercial products
PLA	Fracture fixation [25], interference screws [25], suture anchors, meniscus repair [25], reconstructive surgeries [2], Vascular grafts [27], Adhesion Barriers [28], Articular cartilage repair [29], Bone graft substitute [2,30], Dural substitutes [2], Skin substitutes [2], Tissue augmentation [30], Scaffolds [8]	Proceed™ Surgical Mesh (Ethicon Inc.) , Artisorb™ Bioabsorbable GTR Barrier (Atrix laboratories, Fort Collins, CO, USA)
PLGA	PLGA (Composition 85:15): Interference screws [25], plates [25], suture anchors [25], Stents [38]/(Composition 50:50): Suture [25], drug delivery [25], Articular cartilage repair [39]/(Composition 90:10):Artificial skin [25], wound healing [25], hernia repair [2], suture [2], tissue engineered vascular grafts [2]	Rapidsorb® plates (DePuy Synthes CMF, West Chester, PA,USA), Lactosorb® TraumaPlatingSystem (Biomet, Inc., Warsaw, IN, USA) [l-lactide/glycolide = 82/18], RFS™ Screw System (Tornier), RFS™ (Resorbable Fixation System) Pin System (Tornier), Xinsorb BRS™ stent (Huaan Biotechnology Group, Gansu, China) REF1, Dermagraft®, Vicryl® woven mesh (Ethicon Inc.) (Composition 90:10)
PCL	Suture coating [25], dental orthopedic implants [25], Tissue repair [2], hybrid tissue-engineered heart valves [2], Surgical meshes [2], cardiac patches [31], Vascular grafts [32], Adhesion Barriers [33], Dural substitutes [2], Stents [34], Ear implants [2], Tissue engineering scaffolds [16,35]	Tissue repair patches (Ethicon Inc.), Bulking and Filling agents (Angelo, 1996), DermaGraft™ (Organogenesis Inc., Canton, MD, USA)
PPF	Orthopedic implants [25], dental [25], foam coatings [25], drug delivery [25], Scaffolds [8,12]	-
PPC	Scaffolds [87,88]	-
PHB	Sutures (P4HB polymer) [2], screw fasteners for meniscal cartilage repair, Scaffold for tendon repair [2], Reconstructive surgeries (Surgical	Phantom Fiber™ suture (Tornier Co.), MonoMax® suture

	meshes) [2], Vascular grafts [32], Nerve repair [36,37], Bone tissue scaffold (P3HB) [26], Wound dressing (P3HB) [2], hemostats (P4HB) [2], Stents [38]	(Braun Surgical Co.), BioFiber™ scaffold (P4HB polymer) (Tornier Co.), TephaFlex® mesh (Tepha Inc.) (P4HB polymer), GalaFLEX mesh (Galatea Corp.), Tornier® surgical mesh (Tornier Co.)
PHBV	Scaffolds [89,90]	-
PBS	Stents [2], Sterilization wrap [2], Diagnostic or Therapeutic Imaging	Disposable Medical Products-Bionolle® 1000 and 3000 (Showa Highpolymer Co. Ltd.)

One of the major trends in the pharma sector is that separate disciplines vanish more and more in the bioeconomy. This is generally interpreted as a positive thing, because it promotes synergy. As an example, industrial biotechnology can use various biomass feedstocks to produce, via fermentation, different molecules, such as restriction enzymes or ligases. These are needed to enable various omics technologies such as deep sequencing, in which the molecules are utilised in order to cut genes, for example. This in turn facilitates the development of better health through e.g. personalized medicine approaches to e.g. cancer therapy on the one hand. On the other hand, producing more and more active pharmaceutical agents using biomass instead of petrol should have positive effects on agriculture and the environment, which in turn can improve people's health.

Based on our experience, nova's experts estimate that other future markets for bio-based molecules in the pharmaceutical sector, apart from enzyme production, will be biodegradable bio-based polyesters, which can be used e.g. for tissue engineering applications, drug-delivery solutions and last but not least bio-based molecules that have e.g. antimicrobial properties themselves like some rhamnolipids. In the mentioned applications, some commercial solutions already exist, but their contribution is not yet significant enough to apparently warrant systematic studies on them. Nonetheless, the authors think that in the long run enormous impact in this sector can be achieved. The biggest growth potential in the long run will exist in synthetic biology and metabolic engineering approaches. These will enable the production of APIs using *E. Coli* or yeast cells, modified to contain the plant genes responsible for API production. This way the high costs of extracting only a tiny amount of API from a plant or trying to recreate the plants pathway using multiple petrochemical reactions steps could be lower using production via fermentation.

The most important conclusion is that biopharmaceuticals have a strong standing and will continue to grow after the patents for several blockbuster drugs will have expired by 2019. This in turn will also drive the excipients market to grow. Due to its complexity though, it is difficult to make predictions whether this will directly lead to a higher bio-based share in the excipients segment of the pharma market.

3.3.3 Discussion and identification of gaps

Lacking interdisciplinarity was identified by several papers to be missing to further improve the health sector of the bioeconomy. Another aspect might be pointing out and increasing promotion of using biodegradable and bio-derived options in making medical devices such as using PHA as a degradable and bio-compatible scaffold to regrow oesophageal stem cells on. As shortly indicated above already, the pharmasector uses different terminology for products either extracted from plants or produced by microorganisms. Therefore, a study which combines the existing market research, points out that the bio-based share in this sector is significant and possibly also speaks about the environmental implications by including

e.g. an LCA on these biopharmaceuticals might be warranted. An analysis of the share of bio-based excipients in this sector is also missing.

3.4 Personal and home care

Table 9: Studies relevant to the personal and home care sector

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	SURFACTANTS - A Market Opportunity Study Update	Rust and Wildes, 2008	Very informative and detailed report of the whole surfactants market and all its subsectors. It focuses mostly on US data but makes the distinction between bio-based and petro-based. It states that the annual surfactant demand in the United States is estimated to be approximately 3.85 billion kg. The largest end use market for surfactants is household cleaning detergents. These are comprised of large volume, lower priced laundry and dishwashing detergent commodity products that account for roughly one-half of the U.S. surfactant market. U.S. surfactant production is based on 40 % petro-chemical and 60 % oleochemical (=bio-based) feedstocks.	Rather old with focus on the US but seems to be the only report that is freely available (there are newer reports from commercial market research companies) soynewuses.org/wp-content/ uploads/MOS_Surfactants2009.pd
2	Surfactants from Renewable Resources	Hill, K., 2010	The paper focuses on biosurfactants and their great variety. Using the example of alkyl polyglucosides it also shows that the 12 principles of green chemistry are perfectly adhered to by these molecules. The same example shows its environmental benefits and a wide range of home care applications it can be used in.	onlinelibrary.wiley.com /doi/10.1002/9780470686607.ch4/pdf
3	Rohstoffwandel in der Chemischen Industrie – nur noch eine Frage der Zeit	Hüser, T., 2012	The report talks about markets and potentials of biopolymers and has a paragraph about bio-based cleaning agents. It mentions that their total global production capacity was 17 Mio. tons. It also predicts that the markets will easily grow because of established bio-based products in this sector, their biodegradability and their reduced toxicity compared to petro-based alternatives. Especially the last point is important for the personal/ home care sector where the products often have direct skin contact.	In German www.process.vogel.de /rohstoffwandel-in-der-chemischen-industrie-nur-noch-eine-frage-der-zeit-a-367803/
4	Rhamnolipid biosurfactants—past, pre-	Randhawa, K. and Rhaman P., 2014	The article points out the importance of rhamnolipids for cosmetics and home care applications. Moreover, some crossover exists with pharmaceutical applications due to e.g. their antimicrobial properties.	vbn.aau.dk/en/publications/rhamnolipid-biosurfactantspast-present-and-future-scenario-of-global-market

	sent, and future scenario of global market		Edible emulsifiers such as rhamnolipids can be usable in many applications including food, cosmetic, environmental clean-up and biomedical/natural therapies.	(ccf52a72-26e7-4a45-b1b2-6dc362bdd2d0).html
5	Biosurfactants in cosmetics and biopharmaceuticals	Vavarescou, A. and Iakovou, K. 2015	The paper covers different biosurfactant (BS) molecules and it also shows how they are more superior in their performance than their petro-based counterparts. For instance, over the past two decades the development of BS has been promoted due to their significant interfacial and biochemical properties. Some of them have been established as multi-functional cosmetic materials due to their low toxicity, biocompatibility and dermo-cosmetic i.e. detergency, emulsifying, foaming and skin hydrating and hair repairing properties. Additionally, BS became a viable alternative in the pharmaceutical industry mainly due to their antimicrobial and anti-adhesive properties.	onlinelibrary.wiley.com/doi/10.1111/lam.12440/full
6	Polymers for Personal Care Products and Cosmetics (Vol. 20).	Loh, X., 2016	The book covers the entirety of the personal care market with a chapter dedicated to bio-based products. It names advancement of the technology and higher environmental consciousness of the consumer as main drivers for the market. The chapter also contains an impressive list of bio-based products (see below).	https://books.google.de/books/about/Polymers_for_Personal_Care_Products_and.html?id=FiLBDAAAQBAJ&redir_esc=y
7	Can bio-based chemicals meet demand? Global and regional case-study around citrus waste-derived limonene as a solvent for cleaning applications seeds and flowers	Paggiola, G. et al., 2016	This paper puts into perspective the biomass-supply side to produce limonene (used in home care and industrial cleaning) to answer the question if there is enough biomass to theoretically replace, in their example, the complete demand for toluene as a cleaning agent/solvent. The results clearly show that the potential for complete substitution of toluene by limonene at global level is certainly out of reach, but encouraging results were obtained in specific regional substitution case studies, considering both citrus-producing and citrus-importing countries. In these cases, there is a clear potential for limonene to substitute toluene as a solvent within and beyond the cleaning sector.	Also contains LCA data comparing toluene with limonene. onlinelibrary.wiley.com/doi/10.1002/bbb.1677/full

3.4.1 Key findings of the assessed studies

Hill (2010) and Loh (2016) both show that bio-based materials have a good standing in the personal/home care sector. Table 10 and Table 11 exemplify the great variety of products on the market and the vast range of technologies to produce e.g. bio-surfactants. Apart from the derivatisation of fats and oils to make surfactants, new developments such as sorbitan/sucrose esters and alkyl polyglucosides were identified. The latter also exemplify the superior environmental performance of these molecules because they can be manufactured according to the 12 principles of Green Chemistry (Table 12), whereas petro-based alternatives seldom adhere to all these principles at the same time. Rhandhawa and Rhaman (2014) point out that the rhamnolipid market alone is comparably well developed when considering the bio-based economy as a whole. As an example of this, Table 13 lists various companies who produce these biosurfactants. Taking together the findings of Rust and Wildes (2008) and Hüser (2012), it can be stated that the biosurfactants market is rather big, considering a global production capacity of 17 Mio. tons and a demand of 3.85 billion kg in the U.S. alone. Additionally, Rust and Wildes (2008) also show that 60 % of the total surfactant market is oleochemical and therefore mostly based on oils from palm (kernel) oil, tallow and coconuts.

Table 10: Table of biopolymers and their use in personal care.
Source: Loh, 2016

Biopolymer	Origin	Use in Cosmetics	Manufacturer	Products using the biopolymer
Xanthan gum	Fermentation of whey, corn, wheat, dairy, or soy by bacterium Xanthomonas campestris	Thickener, emulsifier rheology modifier	Cargill, CP Kelco, Aurochemical, Shandong Deosen Corporation, ADM, Jungbunzlauer	Linage Body Moisturizer, Welenda's Calendula Lotion, Lisa Hopeman's Japanese Agarwood Cream
Agar	Red thalloid algae Gelidium and Gracilaria	Thickener, stabilizer, gelling agent,	American Agar Company	
Cellulose gum	Tree pulp and cotton linters	Thickener, emulsifier, film former	Danisco (Zhangjiagang) Textural Ingredients Co. Ltd., Ashland	Olay Regenerist's Advanced Anti-Aging Moisturize Night Resurfacing Elixir
Hydroxyethyl cellulose (HEC)	Tree pulp and cotton linters	Rheology modifier, thickener, stabilizer	Hercules Aqualon, Amerchol Corporation	Olay Regenerist's Advanced Anti-Aging Moisturize Night Resurfacing Elixir
Methyl cellulose (MC)	Tree pulp and cotton linters	Thickener, emulsifier	Jindi Co., Ltd., Qingdao Tianya Chemical	Fiama Diwills Shower Gel, MAC Green Gel Cleanser, Precision Gommage Microperle Eclat Maximum Radiance Exfoliating Gel, Glowfusion™ Micro-Tech™ Intuitive Active Bronzer
Chitin and chitosan	Shells of shrimp and other sea crustaceans	Film former, antibacterial active agent	Jinlong, Golden- Shell Biochemical	Jassen Cosmetics Skin Excel
Gum arabic	Arab gum tree	Emulsifier, thickener	Gum Arabic Processing Company, CNI (Nixera), Agriproducts, A&R (Alland & Robert)	Sukicolor
Hyaluronic acid	Membrane proteins, skin, cartilage, and the vitreous humour	Humectant	Contipro Group, Novozymes, TS Biotech, Dongying Foster Biological Engineering Co. Ltd., Ildong Pharmaceutical	Skin Medispa's Pure Vitality Nourishing Mask
Alginates	Brown algae, seaweed	Thickener, stabilizer	FMC BioPolymer, Alginate Industries Ltd	Zhermack Inc's mask

Polyglu-tamic acid	Fermented soy-bean	Emulsifier, emollient, film former, anti-wrinkle active agent	Shandong Freda Biotech-nology	
Hydroxypro-pyl starch phosphate (HSP)	Starch	Thickener, sta-bilizer	National Starch	Vaseline, Kerastase
Carrageenan	Red seaweed	Rheology modifier, thickener, sta-bilizer, gelling agent, antibac-terial active agent	FMC	
Dextrins	Starch	Active agent carriers	National Starch	Luminizing Moisture Tint by Jouer Cosmetics
Pectin	Citrus fruit and sugar beet	Suarfactant, stabilizers, gel-ling agent		Lakme Peach Milk Moisturiser, Di-apoly's Uroi- Bijin
Gellan Gum	Gram-negative bacteria, Sphin-gomonas elodea	Stabilizer, gel-ling agent	CP Kelco	
Pullulan	Fermentation of starch by fungus Aureobasidium pullulans	Film former, antiwrinkle ac-tive agent		EuokoY-40 Blueprint Resculpting Cream, FANCL Cleansing Powder, Suhada Seikatsu Washing Powder

Table 11: Potential application areas of alkyl polyglucosides in home care products
Source: Hill, 2010.

Application area	**Types of application**	**Properties[a]**
Laundry	Powder detergent Laundry tabs Liquid detergent Special detergent	Liquid laundry Cleaning (dirt/stain removal) Good detergency for special stains (lip stick, oils) Fast penetration into oils and fibres Excellent hydrotrope performance Care – mild to the skin Convenience – rapid dissolution
Dishwash	Manual dishwashing deter-gents	Dishwash and cleaners Excellent emulsification properties for differ-ent types of oily soils to avoid re-soiling Safe to skin
Hard surface cleaners	All-purpose cleaners Bathroom cleaners Kitchen cleaners, power cleaners Glass cleaners, floor cleaners	Streak-free cleaning Good foam profile

	Wipes	
Industrial and institutional	Alkaline industrial cleaners	

[a] Selected properties relevant for the application in home care products.

Table 12: The 12 principles of green chemistry and alkyl polyglucosides
Source (adapted from): Hill, 2010

Principle of Green Chemistry	**APGs are fulfilling this because…**
Prevention – prevent waste instead of clean-up	Fully optimized manufacturing process with the re-use of the excess fatty alcohol
Atom economy – synthetic methods to maximize the incorporation of all materials used	Maximum utilization: reaction 100% – water => >90%
Less hazardous chemical syntheses – reagents and products with low human harm	The process is safe including auxiliaries (no solvent used, see principle 5: proven favourable tox and ecotox data
Designing safer chemicals – guarantee desired function while minimizing toxicity	By introducing glucose, ethylene oxide could be avoided
Safer solvents and auxiliaries – avoid wherever possible	No solvent used in the process; only water for the dilution of the final product
Design for energy efficiency – preferably ambient pressure and temperature if possible	Reaction under ambient pressure and continuous process for the distillation of excess fatty alcohol minimize the energy consumption
Use of renewable feedstocks	Raw materials used are 100% renewable (glucose and vegetable fatty alcohol)
Reduce derivatives – avoid blocking/protection groups, if possible	No protection groups are used
Catalysis	Acid is used in catalytic quantities
Design for degradation – favourable biodegradation properties after use	Design for degradation – favourable biodegradation properties after use
Real-time analysis for pollution prevention – process monitoring	Process control via process information (PI) system
Inherently safer chemistry for accident prevention	Process is inherently safe, no runaway possible due to raw materials

Table 13: Global biosurfactant producers.
Source: Rhandhawar and Rhaman, 2014

S. No.	Company	Location(s)	Product(s)	Focus on
1	TeeGene Biotech	UK	Rhamnolipids and Lipopeptides	Pharmaceuticals, cosmetics, antimicrobials and anti-cancer ingredients
2	AGAE Technologies LLC	USA	Rhamnolipids (R95, an HPLC/MS grade rhamnolipid)	Pharmaceutical, cosmeceutical, cosmetics, personal care, bioremediation (in situ & ex situ), Enhanced oil recovery (EOR)
3	Jeneil Biosurfactant Co. LLC	USA	Rhamnolipids (ZONIX, a bio-fungicide and RECO, a rhamnolipid used in cleaning and recovering oil from storage tanks)	Cleaning products, EOR
4	Paradigm Biomedical Inc.	USA	Rhamnolipids	Pharmaceutical applications
5	Rhamnolipid Companies, Inc.	Usa	Rhamnolipids	Agriculture, cosmetics, EOR, bioremediation, food products, pharmaceutical
6	Fraunhofer IGB	Germany	Glycolipids, Cellobiose lipids, MELs	Cleansing products, shower gels, shampoos, washing-up liquids, pharmaceutical (bioactive properties)
7	Cognis Care Chemicals	China, Germany, USA	Alkyl polyglucoside APG, Plantacare 1200 GLY (green surfactant for use in oral-dental formulations), Rheocare TTA (for cleansing formulations)	Used in formulations for household cleaners, bath/shower gels, dish washing, laundry detergents and in agrochemicals
8	Saraya Co. Ltd.	Japan	Sophorolipids (Sophoron, a low-foam dishwasher detergent)	Cleaning products, hygiene products
9	Ecover Belgium	Belgium	Sophorolipids	Cleaning products, cosmetics, bioremediation, pest control, pharmaceuticals
10	Groupe Soliance	France	Sophorolipids	Cosmetics
11	MG Intobio Co. Ltb.	South Korea	Sophorolipids (Sopholine-functional soap with Sophorolipids secreted by yeasts)	Beauty and personal care, bath supplies e-g-, soaps with new functions
12	Synthezyme LLC	USA	Sophorolipids	Cleaning products, cosmetics, food products, fungicides, crude oil emulsification
13	Allied Carbon Solutions (ACS) Ltd.	Japan	Sophorolipids (ACS Sophor – first bio-based	Agricultural products, ecological research

			surfactant from Indian mahua oil)	
14	Henkel	Germany	Sophorolipids, Rhamnolipids, Mammoslyerthritol lipids	Glass cleaning products, laundry, beauty products
15	Lion Corporation	Japan	Methyl ester sulfonates (MES)	Detergents formulations, cleaning products
16	Lipo Chemicals	USA	Lipmulse Luxe (high-temperature resistance emulsifier)	Skin care, sun-lotions, hair care formulations, thickening polymers, rheological modifiers, natural gums
17	Kaneka Co.	Japan	Sophorose lipids	Cosmetics and toiletry products

Paggiola et al. (2016) name various examples how petro-based solvents can be replaced by bio-based alternatives using the example of toluene being replaced with limonene. The focus of this paper is more towards the supply side and whether there is e.g. enough citrus waste to meet the demand created by completely replacing toluene with limonene as a cleaning agent. The report shows that around 130 million MT of citrus fruits (including oranges, lemons, limes, grapefruits, and tangerines, amongst others) are grown worldwide every year, which could potentially generate a staggering amount of ca. 65 million MT per annum of citrus peel waste (citrus peel accounting for the 50% of the whole fruit). This offers great potential for limonene recovery by extraction. They were able to show that the overall citrus waste production is not enough to meet the global demand but that regional markets can be self-sufficient e.g. Brazil and India. nova's experts estimate that additional limonene production pathways, e.g. using more variable feedstocks through biotechnological limonene production, it could eventually become possible to meet the global toluene demand (as cleaning agent) with bio-based limonene.

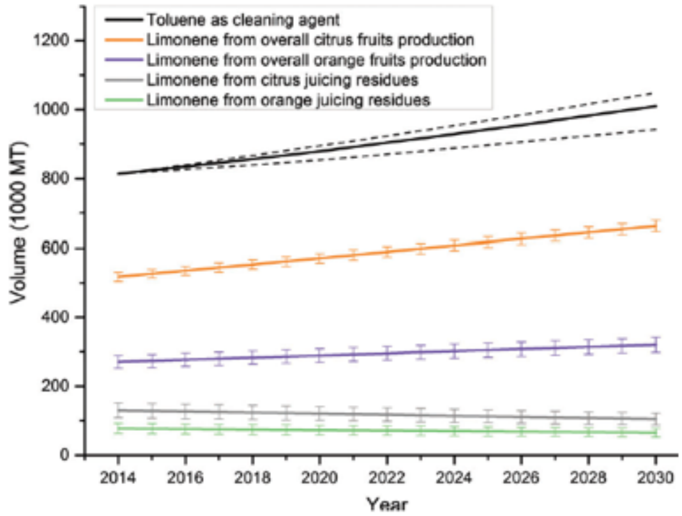


Figure 13: Result of global analysis of substitution potential of toluene (black).
With limonene, as derived from the juicing industry (green=oranges; grey=all citrus juicing) and from overall fruits produce (pruple=oranges, amber=all citrus fruits). Estimated prediction errors represented as dashed lines for toluene. Error bars for limonene forecast. Source: Paggiola, 2016

3.4.2 Trends and emerging markets

Table 8 gives a good, exemplary overview highlighting the improved functionalities of bio-based applications in relation to their fossil-based alternatives. Additionally, many biosurfactants have antimicrobial functionalities which most of their petro-based counterparts do not have. Furthermore, several biosurfactants have been shown to be useful in bioremediation efforts. The latter function offers a new application area to these bio-based products. Apart from summarizing the papers' conclusions, this paragraph will also be based on nova's own experience gained by working for several oleochemical and personal/home care companies. The market for bio-based alternatives and also its prospects is well developed compared to e.g. the bio-based intermediate chemicals market. One reason to explain this phenomenon is that the personal care market is generally characterized by consumers willing to invest more in otherwise comparable products. Furthermore, having an air of "nature/organic" gives bio-based options an extra USP, especially, when it comes to products touching the clients' skin, in addition to providing them with a "green consciousness". One trend should be further market growth for bio-based oils (used for e.g. emulsion formulations) which already have a long standing tradition of faring well, especially in the personal care sector. Further technological and market development of biotechnologically (meaning here to particularly include fermentation) produced surfactants such as rhamnolipids, which can also offer better performance to consumers, should be the biggest trend and market disruption we expect to see in the coming years.

3.4.3 Discussion and identification of gaps

Extensive, all comprising articles which describe the total percentage of bio-based alternatives in the personal/home care market and putting their role into a broader context generally do not really exist. After an extensive literature review and consultation with industry experts, it became apparent that most articles published to date, seem to focus on one subgroup of molecules that can be theoretically made using biomass and are part of a personal care

formulation/product such as biosurfactants and their role in the market. The other fraction of articles deals with a particular subgroup of molecules with a certain set of properties. Therefore, future work could include a report that systematically analyses the wealth of information and research on the various important molecule/functional groups and brings them in the larger context of the personal/home care sector.

Based on previous nova research, we gained the impression that oleochemistry, which often has been bio-based all along, until recently did not really consider itself part of the new umbrella term bioeconomy. This might be also a contributing factor that their part in the personal care market was never systematically analysed with regards to their greater role in the bioeconomy and this sector in particular. The long tradition of oleochemical components in the personal/health care sector might be to its detriment, because compared to relatively newly developed molecules, which do not have a history in the market, rebranding long standing bio-based components in a personal care formulation as “bio-based” and possibly trying to claim GreenPremium prices is rather difficult and possibly not worth investing those companies’ marketing budget for this “re-branding”.

3.5 Food and feed additives

Table 14: Studies relevant to bio-based food and feed additives

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	Food Additives	Pandey, R., Upad-hyay, K., 2012	The paper describes different types of food additives and mentions various sub-categories that come under each classification. It also touches upon the effects of food additives and the additives that has to be avoided according to the Joint FAO/WHO Expert Committee on Food Additives (JECFA). The paper concludes by saying that, all additives are subject to ongoing safety review as scientific understanding and methods of testing continue to improve.	Intech Open Access[11]
2	Food Additives – A Growing Global Market	Thomas, J., 2014	The study describes the key trends and their future effects in the food additive sector. It gives the numbers for global food additive market and explains the key drivers for the market and differentiates between natural and artificial flavours in Europe, Middle East , North America and other regions	Leatherhead Food Re-search[12]
3	Biotechnology of Food and Feed Additives	Zorn, H., and Czermak, P., 2014	This book reviews current trends in modern biotechnology and biochemical engineering with a focus on food and feed additive. It aims at covering all aspects of these interdisciplinary disci-plines, where knowledge, methods and expertise are required from chemistry, biochemistry, mi-crobiology, molecular biology, chemical engineering and computer science. The book is split into 8 major chapters as • Sweeteners • Biopreservatives • Biotechnological Production of Colorants • Acidic Organic Compounds in Beverage, Food, and Feed Production • Industrial Production of L-Ascorbic Acid (Vitamin C) and D-Isoascorbic Acid	Springer

[11] https://cdn.intechopen.com/pdfs-wm/28906.pdf
[12] http://www.foodsciencematters.com/wp-content/uploads/2014/10/Food-Additives-White-Paper-Leatherhead-Food-Research-2014.pdf

			• Amino Acids in Human and Animal Nutrition • Food and Feed Enzymes • Recent Developments in Manufacturing Oligosaccharides with Prebiotic Functions Each and every chapter has its own conclusions mainly describing the current and future trends in the respective additive areas.	
4	Fruit and Vegetable Co-Products as Functional Feed Ingredients in Farm Animal Nutrition for Improved Product Quality	Kasapidou,E., Sossidou, E.,2015	The research shows that fruit and vegetable processing co-products can be effectively used in farm animal nutrition as functional feed ingredients to produce food products of improved quality. It also concludes that commercial application of fruit and vegetable industry co-products, as functional feed ingredients provides challenges and opportunities for field scientists.	MDPI Agriculture Journal
5	A Biotechnological Approach to Microbial Based Perfumes and Flavours	Charu, G., Dhan, P., 2015	This review is an attempt to focus on the potential of microorganisms to be used as small bio-factories for the production of bio-flavours and fragrances. The paper discusses lactones, butyric acid, gesomin, pyrazines and others as flavours and fragrances. This paper concludes that an alternative and attractive route by microorganisms can be safely used for the production of bio-flavours and fragrances.	Medcore Journal[13]

[13] http://medcraveonline.com-/JMEN/JMEN-02-00034.pdf

6	Functional Polymers in Food Science from Technology and Biology	Cirrilo,G., Lemma, F., 2015	This book reviews recent developments in the application of functional polymeric materials in food science. The book mainly reviews the following chapters in detail • Polymers and Food Packaging • Polymers for Food Shelf-Life Extension • Transfer Phenomena in Food/Packaging System • Polysaccharides as Valuable Materials in Food Packaging • Antimicrobial Active Polymers in Food Packaging	WILEY
7	DSM-Nutreco Feed the farmers	Roquas,P., Zoete, K., 2015	This report analyses the value chain of the Animal Feed Industry, its main segments and growth prospects. This report concludes by emnphasizing the mMeeting the local needs of farmers and dealing with complexity are key success factors. Winning feed producers can still grow in mature markets where protein consumption is flat, by offering added value feed solutions at competitive prices.	Rabobank[14]
8	Animal Feed and Feed Additives Market	Transparency research, 2015	The research evaluates the demand and performance of animal feed additives in the global scenario. The research report provides in-depth analysis of current market trends, drivers, and challenges to understand the course of the animal feed and feed additives market over the forecast period.	Transparency Research/ Commercial study

[14] http://www.fromfarmers.eu

3.5.1 Key findings of the assessed studies

A food or feed additive is defined as a type of ingredient "which is intentionally added to a food for a specific technological purpose". For example, to enhance the texture or appearance of a food, or perhaps to act as a preservative by preventing the growth of micro-organisms.

The list of studies provided in this chapter only consider food and feed additives, but no studies on the food industry as a whole, as the main focus of the study are the non-food applications. However, there are a large number of studies in which food and feed production is considered in bioeconomy, but not on additives. The additive studies mainly are on the packaging material where they are used for food packing. These studies are already covered in the packaging segment.

Feed additives

Nutritional feed additives	Non-nutritional feed additives
Amino acids	Antibiotics
Minerals	Hormones
Vitamins	Enzymes
	Immunomodulators
	Probiotics & Prebiotics
	Feed acidifiers

Figure 14: Classification of animal feed additives.
Source: Transparency Market Research

Feed additives now are the main ingredients that are responsible of increasing the yield of worldwide meat production. For improving the overall growth of animals, feed additives are mixed with the basic feed mix. Feed additives act as a catalyst in improving rate of weight gain, prevention of diseases in animals, prevents vitamin deficiencies and improves feed digestion and conversion, thereby improving the quality of meat production. Feed additives are normally used in small quantities for e.g. in injectable, pellets, liquids and powder form. The dosage of the feed additives differs from animal to animal.

Feed additives classified as in Figure 14 are bio-based and are part of bioeconomy strategy documents.

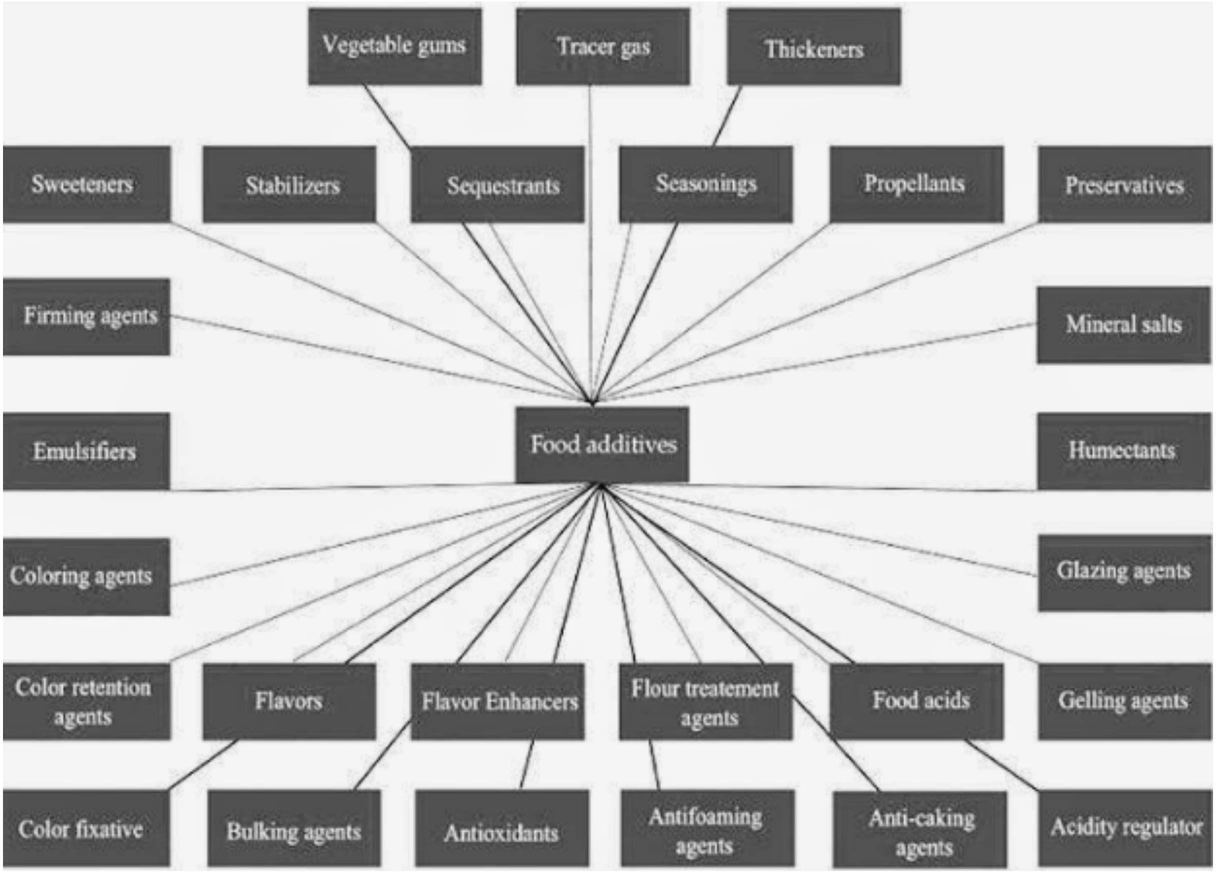


Figure 15: Classification of food additives.
Source: Pandey and Upadhyaya 2012

Food additives are classified as antimicrobial agents, antioxidants, artificial colors, artificial flavours and flavour enhancers, chelating agents and thickening and stabilizing agents (as shown in Figure 15). Antimicrobial agents such as salt, vinegar, sorbic acid and calcium propionate are used in products such as salad dressings, baked goods, margarine, cheese and pickled foods. Antioxidants including vitamin C, E, BHT and BHA are used in foods containing high fats. Chelating agents such as malic acid, citric acid and tartaric acid are used to prevent flavour changes, discoloration and rancidity of the foods. These are all of high importance for food manufacturing companies. The food additives are used to retard spoilage, enhance food flavours, replace nutrients lost in processing and to make the food more visually appealing.

3.5.2 Trends and emerging markets

Trends in the food market

The move to 'natural'

Lately, consumers have been turning away from artificial and synthetic food additives in ever greater numbers, in favour of more natural equivalents. The research from Leatherhood, a market research firm, suggests that in Europe, up to 80% of consumers now prefer their foods to be free from artificial additives. The trend towards natural food additives is most evident within sectors of the industry such as flavours and colours. The desire for more natural food additives has also been a major driver behind the development of stevia-derived

products within the sweeteners sector. With food and drink manufacturers under ever greater pressure to remove or reduce sugar in their products, demand for alternative sweeteners is expected to stay strong.

Health and wellness

The Leatherhood research firm furthermore identifies that the additives industry is also subject to the continued consumer demand for food and drinks which can assist in maintaining health and wellness levels. People around the world are becoming increasingly aware of the relationship between diet and health, and are seeking out food and drinks with lower levels of sugar, salt and saturated fat as a result. This trend has also been largely responsible for the continued growth of the world market for functional additives.

One effect of this trend has been the move by many food manufacturers towards reformulation of their products. As sugar, salt and saturated fats have been removed, opportunities have opened up for suppliers of food additives to develop replacements.

Processed foods in emerging economies

The Leatherhood report also mentions another major market driver as far as food additives are concerned, which is the expansion of the processed and convenience foods industry in less developed parts of the world. As the food industry in regions such as the EU and North America is highly mature, manufacturers of food additives have been forced to look elsewhere in the world for growth.

The Leatherhood report says that it seems likely that more food and drink manufacturers throughout the world will continue to seek out 'natural' and 'clean-label' solutions in order to satisfy consumer demands, as well as catering towards the obligation from the authorities to improve nutritional standards. The health trend is expected to keep demand for food additives such as antioxidants, sweeteners, fat replacers and functional food ingredients at reasonably high levels.

Trends in the feed additive industry

Key growth drivers for the feed industry, include the aim:

- to bring animals up to weight as quickly and cheaply as possible,
- to improve animal welfare and to reduce antibiotic growth promoters,
- to minimize the environmental pressure,
- to maximize food safety and traceability
- to deal with increased raw material price volatility

Focus areas of the feed industry which can be improved by feed additives

- Improve utilization of feedstuff nutrients
- Amino acids to fine tune protein supply
- Reduce the use of antibiotic growth promoters

According to the Rabobank report, the increased focus outside Europe on the reduction of in-feed antibiotic usage creates opportunities for organic acids, robotics, prebiotics and phytogenic (plant-derived) products. The report also suggests, farming practises in the Americas and Asia however restrict the uptake of feed additives. This is partly due to the historic focus on financial performance as opposed to maximising technical performance and the abundant availability of relatively cheap agricultural commodities.

Asia has only just started professionalizing its livestock industry and as such there are still plenty of opportunities to improve farming practices. Rabobank report confirms that before investments in improved climatic conditions and farming practices are made, the added value of the specialty additives will not materialize.

3.5.3 Discussion and identification of gaps

Though there are a large number of studies in the area of researching different food and feed additives categories like antifoaming, antioxidant, emulsifiers and other, there are lack of studies to integrate these into bioeconomy. However, food and feed additives have been a key mention in almost all the bioeconomy papers published by a specific country or as whole at the European level, being described as strategically important or having a big potential. It is quite interesting that there are numerous general claims about the strategic potential of this class of materials, while there is so little knowledge available on volumes, markets, economic and technological feasibility, value chains and resources. In the opinion of the authors of this report, it might be worthwhile to investigate more.

3.6 Construction and furniture

Table 15: Studies relevant to the construction sector

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	Ökobilanz-Basisdaten für Bauprodukte aus Holz	Rüter, S., Diederichs, S., 2012	Comprehensive life cycle assessment (LCA) datasets were generated within the framework of this study, for building products made from wood, which meet the latest standard requirements for use in the field of sustainable construction. In close cooperation with organizations and companies in the German woodworking industry, the life cycle inventory data for 19 solid wood and engineered wood product categories were recorded and their life cycle impact was assessed according to DIN EN ISO 14040. The datasets – verified by an independent critical review – meet the methodological and qualitative requirements of EN 15804:2012 and can be used in environmental product declarations for wood products by the participating companies and associations. (316 pages)	Available in German only
2	Current State of Knowledge on the Hygrothermal Behaviour of Bio-based Materials	Ecomat, 2013	The document is to present an inventory of the publications concerned with the hygrothermal behaviour of materials and bio-based construction products, as well as present, in a summarized form, the main results from these studies.	Ecomat
3	Use of Bio-based Building Materials: Perceptions of Swedish Architects and Contractors	Markström, E., Bystedt, A., Fredriksson, M., Sandberg, D., 2014	This study is intended to contribute to the understanding of the probability that bio-based materials are chosen in residential buildings and to the understanding of the drivers and barriers for an increased use of bio-based building materials. Green building certificates, as well as other environmental standards and regulations were seen as a promising way to increase the use of bio-based materials. Evidence that the materials maintain a certain quality over time was also identified as an important measure to increase the incentives to select bio-based materials.	Forest Products Journal

4	10 recommendations for stimulating bio-based building materials	De Mey, V., Verhoeven J., Thoelen P., van Dam, J.E.G., Meyskens, S., Schik, W., 2015	This project analyses the supply chain of flax and hemp building materials from production of raw material to the production and implementation of end products. It became clear that most stakeholders face the same problems and challenges. In this policy note, the issues are listed with suggestions provided for politicians (9) and other stakeholders (2).	European Union and the Province of West-Flanders.
5	Reducing the Environmental Impact of Construction by Using Renewable Materials	Lawrence, M., 2015	This paper highlights the fact that the targets set by the Kyoto Protocol are primarily being met by the reduction of in-use energy, and that the implications of that are that the energy embodied in buildings will increase in significance from its current 17% level to 50% by 2050. It is evident that the more energy efficient buildings become, the greater becomes the importance of the embodied energy of the materials making up the fabric of the building. The contribution that can be made by bio-based materials is therefore of growing importance.	University of Bath (ISO-BIO project)
6	Baustoffe aus nachwachsenden Rohstoffen	FNR, 2015	Comprehensive 100 page overview of bio-based materials in construction: wood in construction, facades, windows and doors, insulations materials, flooring and decking, paints and furniture.	Available in German only (www.fnr.de)
7	Market entry barriers for bio-based products	Dammer, L. et al., 2015	Deliverable 5.3 of the KBBPPS project analyses market entry barriers for bio-based products resulting from standards and norms. It contains a case study on bio-based insulation material and illustrates different technical issues which are not adequately covered by the existing standards, thus constituting a market disadvantage for bio-based insulation materials.	Project website[15]
8	AUSBAUEN UND GESTALTEN mit nachwachsenden Rohstoffen	FNR, 2016	Comprehensive 100 page overview of bio-based materials for flooring and decking, coating and painting, interior walls, window frames, furniture and wood- and bio-based in construction.	Available in German only (www.fnr.de)

[15] http://www.biobasedeconomy.eu/media/downloads/2015/08/D5_3_Market-entry-barriers.pdf

9	Fire Safe Use Of Bio-Based Building Products	Schmid, J., 2017	This book contains proceedings of the annual COST Actions meeting in Prague on the topic of fire safe use of bio-based building materials. It includes 17 abstracts from different themes covering the topics of technical working groups of the COST action FP1404 and 1 abstract covering the report from training school held at University of Edinburgh.	Cost FP 1404
10	Nordic Bioeconomy, 25 CASES FOR SUSTAINABLE CHANGE	Nordic Council of Ministers, 2017	According to Trefokus, wood-based solutions in construction can lower CO_2 emissions by 50% compared to other building materials. The more traditional use of wood as construction materials is furthermore an important driver for sustainable buildings. Taken together, replacement is, therefore, an important pillar in the Nordic bioeconomy in which biomass is not only used to produce energy, heat and fuel but replace a wide range of unsustainable products.	

3.6.1 Key findings of the assessed studies

"Construction and furniture", also summarized as "Forest-based Industry" in Figure 19, are the second biggest bio-based sector in the economy after "Pulp and Paper", in terms of turnover. Wood is by far the most important bio-based material in construction and furniture. Also, traditionally wood was the most important construction material next to minerals, and for sure the most important in furniture. In the last decades, minerals and new materials such as metals and plastics have won growing shares in the construction and furniture sector. Campaigns funded both by public agencies and industry, increasing consumer awareness as well as new wood processing technologies and new bio-based materials are now leading to new growth for bio-based solutions in construction and maintaining high shares in the furniture industry.

A wide range of wood- and bio-based materials and products are used in construction and furniture:

- House wall and roof construction, multi-storey buildings, apartment buildings (wood)
- Interior walls and furniture (particle board, OSB, MDF)
- Insulation material (wood and cellulose fibres, natural fibres, animal fibres, straw, grass, cork, sea grass and many others natural materials; including biopolymer foams (for example PLA); share of bio-based in the entire insulation market < 5%.
- Flooring, decking and facades (parquet, laminate, WPC, biocomposites)
- Wooden window frames and doors
- Paints, glues, coatings (natural oil and waxes, bioplastics)

3.6.2 Trends and emerging markets

Wood- and bio-based construction materials have a positive, environmental and health friendly image in the public. They are considered natural and green materials. Sustainable buildings often have a high share of bio-based materials, especially in the interior. This has mainly three reasons:

- High sustainability compared to mineral, metal or petrochemical materials, lower carbon-footprint, carbon storage
- Pleasant living climate in the houses, bio-based materials often better regulate moisture contents in a room
- Less harmful emissions compared to synthetic, petrochemical materials

Improvement in wood processing, new construction concepts for timber, newly developed paints and glues, insulation materials and biocomposites offer new products and allow additional applications. Further growth is expected, especially in wooden multi-storey buildings.

With the discussions about circular economy and cascading use of biomass in the last years, there was an increasing interest in bringing more wood in construction instead of using it just for bioenergy. Especially Northern countries have issued clear statements about the importance and potential of wood construction. The Minister of Economic Affairs in Finland,

Olli Rehn, said in 2015: "The greatest potential for growth in wood use lies in construction of new apartment buildings, energy repairs to facades of suburban multi-storey buildings and construction of additional storeys, hall-like buildings, wooden bridges as well as yard buildings and landscaping"[16].

3.6.3 Discussion and identification of gaps

Unsuitable standards and norms are still a barrier for the further market growth of bio-based constructions products. Several cases have been identified.

As an example, natural fibre insulation faces the following problems: “The different behaviour of natural fibre insulation in terms of moisture content leads to another paradox situation: In some EU Member States, moisture permeable materials (vapour open construction) are not allowed as insulation in buildings at all. These regulations do not recognize that bio-based insulation is perfectly happy to become moist temporarily and still perform thermally and even provides advantages compared to moisture tight insulation, since it serves to better regulate moisture contents in a room and to minimize the risk of condensation and mould growth. Only conventional insulation materials producers profit from the current regulations, while natural fibre insulation manufacturers and consumers suffer unfairly from them.” (Dammer et al. 2015)

Wood construction and furniture have not been in the focus of the research agenda of the bio-based industries so far, which looks more at biotechnology, new feedstocks, new chemicals and materials – such as glues, paints, coating and biocomposites.

Nova experts see further potential in the development of wood construction technologies in combination with industry 4.0 technologies.

Due to the comprehensive incentive framework for bioenergy, there is a non-level playing field between bioenergy and the construction sector, which can have local impacts on the availability and costs for wood.[17]

[16] http://www.woodproducts.fi/articles/minister-rehn-wood-construction-part-bioeconomy-development

[17] nova-Paper #4 on bio-based economy: “Proposals for a Reform of the Renewable Energy Directive (RED) to a Renewable Energy and Materials Directive (REMD)”, www.bio-based.eu/nova-papers

3.7 Packaging

Table 16: Studies relevant to the packaging sector

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	Untersuchung der Umweltwirkungen von Verpackungen aus biologisch abbaubaren Kunststoffen	IFEU-Institut for Umweltbundesamt, 2012	A market survey was carried out which revealed a share of max. 0.5% of bioplastics packaging of the overall German plastics packaging market. This showed that the market incentive for bioplastics achieved through the special provisions was marginal. It was expected that the share of bioplastics packaging would increase to roughly 1%-2% in the period between 2011 and 2015 (a follow-up to this forecast was not found). There is also a marked trend towards plastics packaging which are biobased but not biodegradable. Existing life cycle assessment (LCA) studies often show smaller impacts for bioplastics packaging as compared to their fossil-based counterparts when it comes to greenhouse gas emissions and fossil resource consumption. However, when looking at a broader range of environmental impact categories, bioplastics, in most cases, do not achieve an overall environmental superiority over the fossil-based counterparts. Compostable bioplastics packaging contains shares of fossil-based copolymers and usually are heavier in weight. LCA results of this group of bioplastics packaging therefore may even show an unfavourable overall environmental performance as compared to the fossil-based counterparts. Environmental optimisation potentials of bioplastics packaging are found in the area of biomass production (selection of adequate crops, improvement of farming operations, use of residual biomass or lignocellulose) as well as in the area of biomass conversion (improved energy efficiency and product yield).	Available in German only[18]
2	Life Cycle Assessment of end-of-life options for two biodegradable packaging materials: In support of	Rossi, V. et al., 2012	The publication has interesting and important results on different end-of-life option, showing that the EU Waste Hierarchy is not always valid for biodegradable plastics, especially looking at the benefits that can be expected from composting: "For most indicators, mechanical recycling appears as the preferred end-of-life option, in line with the EU Waste Hierarchy. The direct fuel substitution in industrial facility also appears as an interesting option, competing with recycling from an environmental perspective. On the other hand, composting has higher impacts	Link here[19]

[18] https://www.umweltbundesamt.de/sites/default/files/medien/461/publikationen/3986.pdf
[19] http://avnir.org/documentation/book/LCAconf_rossi_2012_en.pdf

	flexible application of the European waste hierarchy		than municipal incineration, while the Waste Hierarchy suggests a preference for composting compared to municipal incineration. Anaerobic digestion lies between municipal incineration and direct fuel substitution, within the group of end-of-life options that recover energy. Finally, landfill does not provide important benefits, but has very low impacts for most indicators, even lower than composting, in clear contradiction with the Waste Hierarchy, except in the case of TPS for global warming: the degradation of this material in landfill could cause large amounts of methane emissions, dominating all other end-of-life options. … The EU Waste Hierarchy should be taken with care for these materials: its concept is a good general rule, but a full life cycle assessment is advised before making a final decision".	
3	Biobased Packaging Catalogue	Molenveld, K. et al. (Wageningen UR), 2015	The purpose of the 134 page catalogue is to showcase biobased packaging products and provide an overview of commercially available biobased packaging in 2014. This catalogue is a translation of the Dutch version of the biobased packaging catalogue that was launched September 2014. The raw materials, products and services related to biobased packaging products are categorised wherever possible according to their application and described in brief. Some types of packaging consist partly of biobased materials and partly of non-biobased materials due to specific functional requirements. In such cases, the percentage of biobased content is stated. Wherever possible, references to producers and suppliers are given.	Link here[20]
4	Market study on the consumption of biodegradable and compostable plastic products in Europe 2015 and 2020	Kaeb, H. et al., 2016	Compostable plastic bags, mainly used for shopping or biowaste collection, dominate the market for biodegradable plastic products in Europe. They make up about two thirds of the total market of 100,000 t (error range 90,000 - 110,000 t) of biodegradable plastic products sold in 2015. The market of compostable and biodegradable plastic products could grow to beyond 300,000 tonnes in 2020 – if the legal framework were to be set more favourably. The legal framework and composting infrastructure of EU member states were found to be either the bottleneck or the key driver for market development.	Commercial report, free short version available at www.bio-based.eu[21]
5	The new plastics economy – Rethinking the future of plastics	Ellen MacArthur Foundation, 2016	Although the report cannot live up to the high expectations of its title, it contains a comprehensive assessment of the worldwide plastic flows with a focus on the packaging market. The focus is a circular economy for all kind of plastics and especially for the packaging sector: "The report outlines a fundamental rethink for plastic packaging and plastics in general; it offers a new approach with the potential to transform global plastic packaging materials flows and thereby	Link here[22]

[20] http://edepot.wur.nl/343774
[21] http://bio-based.eu/download/?did=49444&file=0
[22] https://www.ellenmacarthurfoundation.org/assets/downloads/The-New-Plastics-Economy.pdf

			usher in the New Plastics Economy, offering a new vision, aligned with the principles of the circular economy, to capture these opportunities”. The topic of bio-based materials is only a side note in the report, compostable packaging is discussed as a solution for certain applications: “Scale up the adoption of industrially compostable plastic packaging for targeted applications such as garbage bags for organic waste and food packaging for events, fast food enterprises, canteens and other closed systems, where there is low risk of mixing with the recycling stream and where the pairing of a compostable package with organic contents helps return nutrients in the contents to the soil.”	
6	Bio-based Building Blocks and Polymers Global Capacities and Trends 2016–2021	Aeschelmann, F. et al., 2017	Strong political support can only be found in Italy and France for biodegradable solutions in the packaging sector. In this sector, the global demand for biodegradable packaging still shows a double digit growth. Additional demand could come from the increasing microplastic problem (marine littering), but so far biodegradable plastics have not benefitted from this debate. Most bio-based polymers are consumed by the packaging industry. The major part of this is rigid packaging (bottles and others) and the rest as flexible packaging (films and others). This is not surprising since bio-based PET (mostly used to produce bottles) is one of the biggest bio-based polymers in terms of capacity. The packaging industry has a considerable interest in biodegradability since packaging is only needed for short time use but in big quantities. This contributes to the accumulation of waste. Biodegradable polymers can be one possible solution to solve this problem. The biodegradation of different polymers takes place in different environments; some polymers need industrial composting, others work also in home composting and a limited number also in soil, fresh water or even in the ocean. Therefore, biodegradation of polymers is also interesting for agriculture and horticulture applications (e. g. mulch films).	Commercial report, free short version available on www.bio-based.eu[23]
7	**Bio-based and biodegradable plastics – Facts and Figures** Focus on food packaging in the Netherlands	De Oever, M. et al., 2017	The report gives a comprehensive overview on: “Just like fossil based plastics, bio-based and/or biodegradable plastics are available in many grades with a wide variety of properties. The suitability of bio-based and/or biodegradable plastics for particular applications depends on these properties. Also the most suitable end-of-life option depends on its properties.” Data on production, availability, technical properties, LCA and end-of-life.	

[23] http://bio-based.eu/media/edd/2017/03/17-02-Bio-based-Building-Blocks-and-Polymers-short-version.pdf

3.7.1 Key findings of the assessed studies

Packaging is the biggest application sector for plastics in general and increasingly important for pulp and paper (see chapter on pulp and paper).

Figure 16 shows that rigid and flexible packaging together are the most important application sectors for bio-based and also biodegradable plastics.

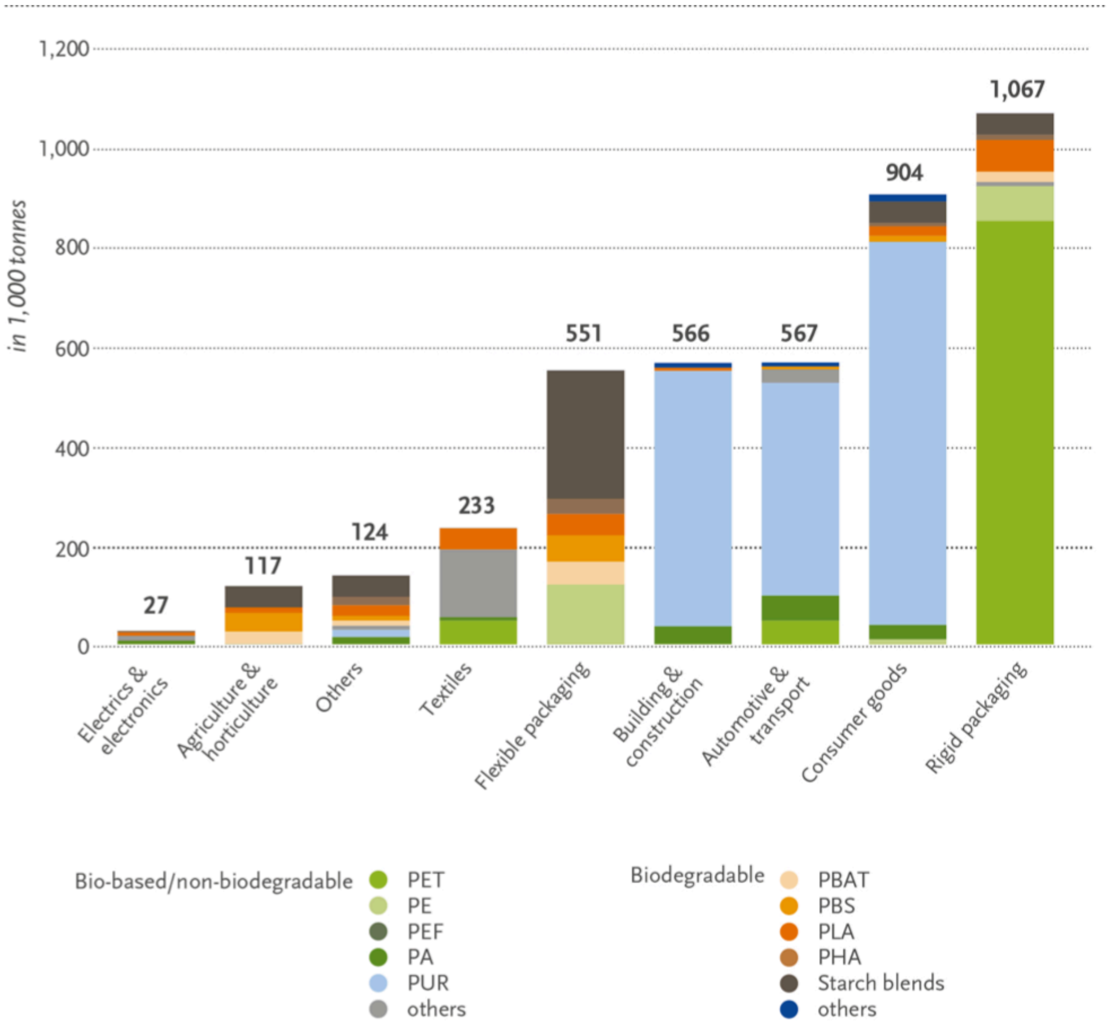


Figure 16: Global production capacities of bioplastics 2016 (by market segment)
Source: Aeschelmann et al. 2017

The next figure shows that packaging accounts for 89% of all applications for biodegradable plastic products. The most important bio-based polymers in packaging are starch co-polyester compounds, PLA and PLA co-polyester compounds.

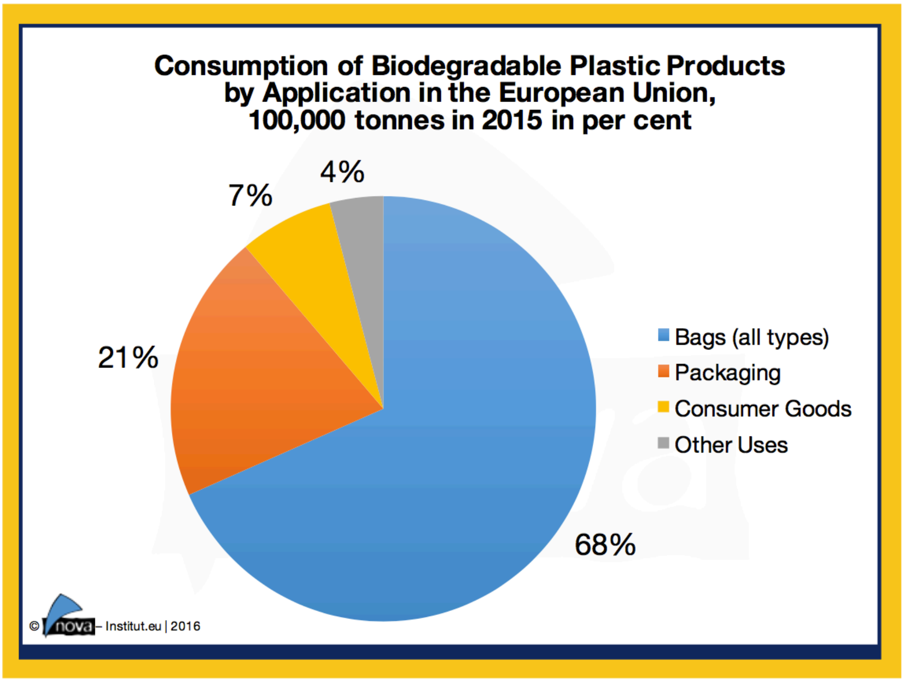


Figure 17: Consumption of Biodegradable Plastic Products by Application in the European Union, 100,000 t tonnes in 2015 in per cent.
Source: Kaeb et al. 2016

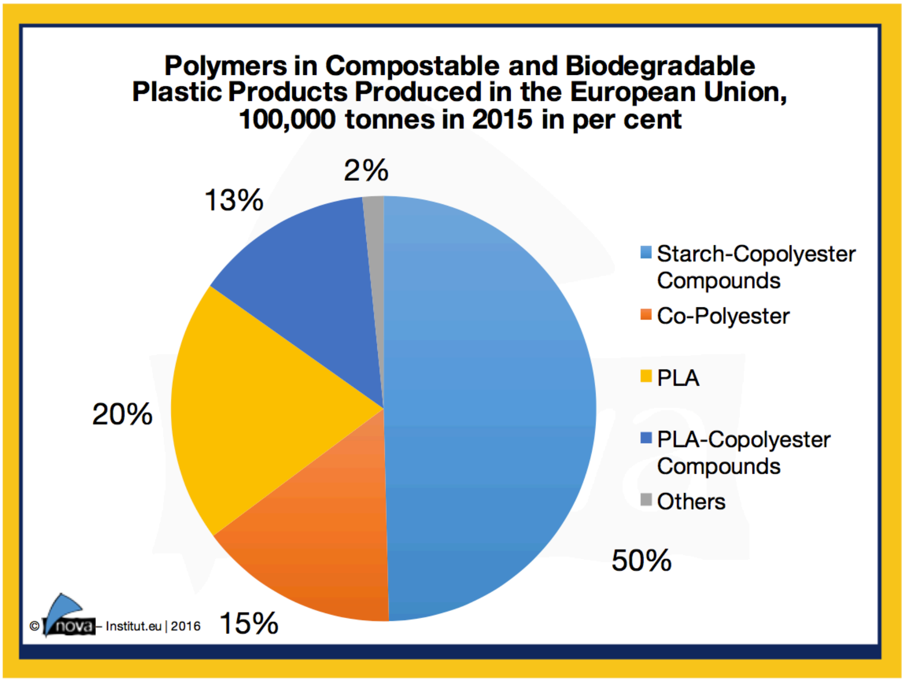


Figure 18: Polymers in Compostable and Biodegradable Plastic Products Produced in the European Union, 100,000 tonnes in 2015 in per cent.
Source: Kaeb et al. 2016

There are mainly three types of bio-based packaging on the market:

1. Paper, board and other wood-based (and to small shares natural fibres and other lignocellulosic materials) packaging products. Packaging of consumer goods, electric and electronic equipment, all kinds of goods, also shopping bags. Why: Mechanical properties, price, recycling/cascading use and lower GHG footprint.
2. Drop-in bio-based polymers such as bio-PET (mainly for rigid bottles) and bio-PE (mainly for flexible packaging). Why: Lower GHG footprint compared to fossil counterparts.
3. New bio-based polymers. Why? Lower GHG footprint, special properties and functionalities such as special barrier properties or biodegradation (home and industrially compostable, biodegradation in soil). A new promising polymer for the packaging sector is PEF, developed in Europe (Avantium, The Netherlands), first production is supposed to take place in Belgium with BASF (Germany).

3.7.2 Trends and emerging markets

The packaging sector is the largest market for entire plastics applications. Political targets of the packaging sector are: Avoid, reduce and recycle. But also materials with a lower environmental footprint are welcome and for some applications, also biodegradation is a favourable end of life option. In both cases, bio-based packaging material can be an interesting option.

The correlation between framework conditions and market success of bio-based packaging is very high and also strongly affects future projections. Biodegradable plastic markets have become political markets to a large extent, with "bagislation" as a semi-formal term coined to express the specific legislation around plastic bags which have become of special interest to law-makers. A positive framework, such as in Italy or France, will guarantee market growth and investments; a negative setting, such as in Germany, will put successful developments at stake.

Example Italy (Kaeb et al. 2016):

- Italy banned non-compostable plastic carrier bags in 2011. Leading to a plastic bag reduction from 180 kt (2010) to 104 kt (2014)
- Law created a 35 kt pa market for biodegradable plastics (potential: 50 kt)
- IT banned very lightweight plastic packaging bags, starting on 1.1.2018. Exemption for compostable and partly % bio-based plastics (similar to France)
- EU notification started 12-2016 (stand still period)
- EU Packaging and Packaging Waste Directive "Bagislation" (April 2015) helped to maintain the IT bagislation formerly perceived as harsh & discriminating. EU allowed EU Member States to choose from a wide range of measures to achieve the reduction targets set for lightweight plastic bags, and derogate from EU scope as well (e.g. tackle very lightweight plastic bags)
- IT in combination with FR bag legislation have created the biggest individual product market for biodegradable & compostable plastics (market study nova, 2016)
- Political motivation was built on:
  - Waste goals: Reduction, improved separation, increased organic recycling
  - Economic goals: (Re-) Industrialization & bio-innovation (in chemistry/plastics)

Example France: "As part of the new law on Energy Transition and Green Growth, and in line with the EU Directive on the reduction of plastic bags, France banned single-use plastic bags[24] at cash registers in France as of July 2016 except for bags that are bio-based and home-compostable. From 1 January 2017 on, single-use plastic bags for other uses than at the cash register, including fruit and vegetable bags, that are below a thickness of 50 microns, will have be home-compostable and feature a bio-based content of at least 30 percent as well. In September 2016, France went yet another step further and banned disposable plastic plates, cups, and utensils by 2020, except for ones made from bio-based and home-compostable plastics." (http://www.european-bioplastics.org/these-were-the-highlights-that-shaped-bioplastics-in-2016/)

The framework is still in the making in most EU Member States, and also on EU level. The European Parliament's plenary vote on amendments of the Packaging and Packaging Waste Directive encourages Member States to support the use of bio-based materials for the production of packaging and to improve market conditions for such materials and products. (http://docs.european-bioplastics.org/PR/2017/EUBP_PR_MEPs_pave_way_for_bioplastics_20170314.pdf)[25]

3.7.3 Discussion and identification of gaps

There are several gaps identified by nova experts – based also on previous research and exchange with industry experts – acting as hurdles and barriers for the further growth of bio-based packaging materials:

1. There is no common understanding, agreement or strategy on the question which bio-based and/or biodegradable plastics can and should play a role in sustainable packaging and the circular economy. The understanding and political framework differs from one member state to the other. What are the criteria for good and sustainable packaging? Can bio-based and/or biodegradable plastics offer special solutions?
2. Low expertise and trust in existing standards and labelling on biodegradation in different environments. Although significant progress has been made over the last few years, additional scientific and standardization work, labelling and communication are crucial for further development (e.g. in the areas of biodegradation in fresh and marine water, see Open-Bio results).
3. Very limited knowledge in the public, politicians and NGOs concerning the assessments of the properties, opportunities and benefits of bio-based and/or biodegradable plastics today in specific applications.

[24] http://www.european-bioplastics.org/french-decree-supports-bio-based-and-home-compostable-bags/
[25] http://docs.european-bioplastics.org/PR/2017/EUBP_PR_MEPs_pave_way_for_bioplastics_20170314.pdf)

3.8 Pulp and paper

Table 17: Studies relevant to the pulp and paper sector

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	Employment and value added – a comparison between European Pulp and Paper Industry and the Bioenergy Sector	CEPI (Confederation of European Paper Industries), 2011	Analysis of value added, employment and investment in the pulp & paper sector in comparison to the bioenergy sector. The result: A comparable investment (in terms of wood consumption) creates nearly 5 times more wealth (value added, employment) in the pulp and paper industry than in bioenergy.	The result is in line with calculations in other sectors, comparing the impacts of material use to bioenergy.
2	Resource efficiency = cascading use of raw material	CEPI (Confederation of European Paper Industries), 2012	When looking at job creation in a sector that is part of the bio-economy, the pulp and paper industry value chain creates 7 jobs for every job created by the energy alternative. In absolute terms, the pulp and paper industry value chain creates 1,597,200 jobs, while the energy alternative rests at 238,800 jobs. The wealth creation in the pulp and paper industry value chain is mainly market driven and 5 times that of the energy alternative.	
3	A BLUEPRINT FOR THE EU FOREST-BASED INDUSTRIES (woodworking, furniture, pulp & paper manufacturing and converting, printing)	COMMISSION STAFF WORKING DOCUMENT, 2013	The European pulp and paper manufacturing and converting industries employ around 647,500 workers in 21,000 companies, generating an annual turnover of around 180 billion Euro, from the production of pulp as well as graphic, hygienic, packaging and specialised paper grades and products. Overall paper consumption in Europe has stagnated, due to the economic slowdown and also structural developments. A continuing decrease in graphic paper consumption is expected as a result of the growing pace of digitalisation and changing lifestyles. However, this is counter- balanced by growth in packaging and hygiene papers, mainly due to demographic trends	

			in Europe. Innovative business models and products create new opportunities for the sector, however, these require new skills and education. The pulp and paper sector is increasing its share of exports outside the EU. Even so, tariff barriers, applied to nearly half of the exports and protectionist subsidies for rival goods, create an uneven playing field, further restricting market potential. The European pulp and paper sector is seizing the opportunities of a bio-based economy. New business concepts will allow it to use the entire potential of the raw materials and by-streams of the forest-based sector efficiently to produce a broad range of high added-value products and novel materials for use in the textile, food and pharmaceutical industries, bio-based fuels and chemicals, alongside traditional wood-based products.	
4	Study on the Wood Raw Material Supply and Demand for the EU Wood-processing Industries	Indufor, Helsinki, Dec. 2013	The total amount of pulp produced in the EU is 36 million tonnes. Most of the pulp produced in the EU is chemical pulp. Its production in 2011 was at the same level as in 2000, some 10% below the peak of 2006. The production of both mechanical and semi-chemical pulps in 2011 was below the 2000 levels by 10% and 13%, respectively. Production is expected to decrease further, along with the change from paper to electronic media. Most of the EU pulp trade (90%) is chemical pulp. Pulp imports grew in the 2000s by 3% and imports are expected to continue to expand with the increased low-cost production capacity in Latin America. The share of chemical pulp is quite steady at about 70% of all virgin pulp consumed and the share of mechanical pulp about 25%. Consumption of mechanical pulp has decreased slightly faster than consumption of chemical pulp because of the decrease in the production of the publication papers. The share of dissolving pulp is 1-2%, increasing towards 2011. The reasons for the growth lie with the rising consumption of textile fibres, increasing price of cotton and the acceptance of viscose fibres as a natural product.	

5	Multi-perspective application selection: a method to identify sustainable applications for new materials using the example of cellulose nanofiber reinforced composites	Piccinno, F.; July 2015	Using an example of cellulose nanofiber reinforced composites, the authors illustrate the procedure whereby luxury consumer goods, specialty vehicles, industrial processing and furniture result are the most promising applications. The results give the researchers a more holistic understanding of their material and help to establish the requirements that the material must fulfil for the selected application. With that knowledge, the method can help enact development pathways in applied materials research.	

3.8.1 Key findings of the assessed studies

With a share of 30%, pulp and paper is the biggest sector of the bio-based industries (see Figure 19) in terms of turnover as well as material volumes used and processed. The raw materials are mainly bio-based, wood (and to small extent also other natural cellulose fibres) and starch as an additive to achieve the desired paper quality. Nevertheless, the sector is not really aware to be part of the bio-based industry. New lignocellulosic biorefineries serve as a bridge between the traditional pulp and paper and new chemical sector.

European Commission 2013: “Overall paper consumption in Europe has stagnated, due to the economic slowdown and also structural developments. A continuing decrease in graphic paper consumption is expected as a result of the growing pace of digitalisation and changing lifestyles. However, this is counter-balanced by growth in packaging and hygiene papers, mainly due to demographic trends in Europe. Innovative business models and products create new opportunities for the sector, however, these require new skills and education.” The whole sector is under continuous pressure. The consumption of graphic paper for newspapers, magazines and books is decreasing, other sectors such as packaging and hygiene papers show growth. Also, the production of dissolving pulp for cellulose fibres shows a strong increase (please see also chapter on textiles).

The development on nanocellulosic material offers a wide range of new applications, such as films, but only a few have reached first niche markets.

Several studies show that the pulp and paper sector is correlated with much stronger impacts on employment, turnover and value added than wood-based bioenergy (per tonnes of wood, see chapter 4). On the other hand, all incentives are for bioenergy and none for pulp and paper. Authors ask for a level playing field to realise the potential of the pulp and paper sector and to support the transformation of the whole sector.

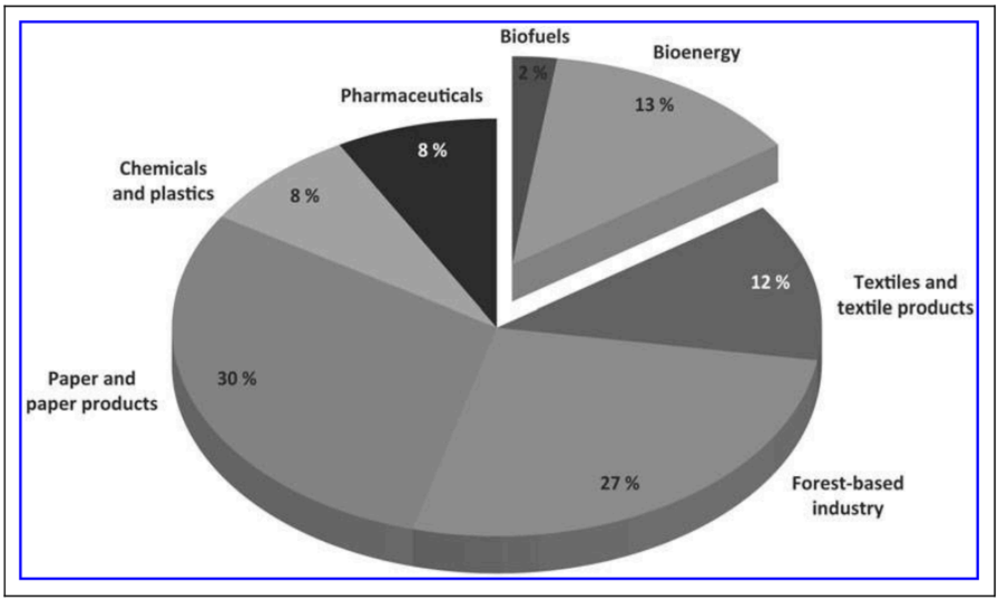


Figure 19: Turnover in the EU bio-based economy, excluding agriculture, forestry, fishery, food, beverages, and tobacco products (2013 total: € 600 billion).
Source: Piotrowski et al. 2016

3.8.2 Trends and emerging markets

From volume, infrastructure and biomass supply, the pulp and paper sector is and will be one of the most important parts of the bio-based industry. Because of fast changing markets and new technology options, the whole sector is undergoing significant development towards modern and fully integrated lignocellulosic biorefineries. Different kinds of chemical pulp incl. dissolving pulp will continue to be one of the most important outputs. But in addition, a full range of new cellulose materials (nano, fibres) and chemicals (through pathways starting from tall oil, via fermentation from C5 and C6 sugars, or by using harsh chemical acids) will be produced, increasing the total value from wood and the resource efficiency.

The worldwide demand for environmentally friendly packaging and hygiene papers will grow strongly in the coming years and decades. New technologies even allow to enter additional applications in packaging (for example shopping bags) and hygiene papers. The political debate on microplastics in the marine environment will put pressure on plastic solutions and strengthen the demand for paper-based packaging and hygiene papers.

Pulp and nanocellulose can also be used in combination with (bio)plastics in biocomposites for example for furniture or toys (Piccinno 2015).

Drivers of the development are the pulp & paper companies, the forest industry and countries with high importance forest and wood-working industries, such as Sweden and Finland.

3.8.3 Discussion and identification of gaps

Many new lignocellulosic biorefinery concepts were developed in the last years. What was missing was the link to the existing pulp industry. How can large volumes of biomass, well-developed infrastructure, efficient processes and excellent expertise in the cellulose processing be used to build modern biorefineries with cellulose and chemicals?

Wood can be used for so many processes and applications such as: Construction, furniture, biocomposites, textiles, pulp & paper, a wide range of chemicals (through pathways starting from tall oil, via fermentation from C5 and C6 sugars, or by using harsh chemical acids), biofuels, bioenergy and many more. It would be interesting to find out which utilization pathways are the most promising for GHG reduction, other environmental impact categories, value added or employment.

3.9 Bioenergy and biofuels

Table 18: Studies relevant to bioenergy and biofuels

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	Renewable energy progress report	European Commission, 2013	The purpose of this report is to assess Member States' progress in the promotion and use of renewable energy along the trajectory towards the 2020 targets and to report on the sustainability of biofuels consumed in the EU and the impacts of this consumption in accordance with the Directive. The report shows a slower than expected removal of key barriers to renewable energy growth, with additional efforts by particular Member States being necessary. Deviations from national plans increase the regulatory risk faced by investors and barriers that should, but have not yet been addressed through the implementation of the renewable energy Directive, remain to be overcome. At EU and Member States level, further efforts are needed in terms of administrative simplification and clarity of planning/ permitting procedures and for infrastructure development and operation.	Reports on policies affecting the whole renewable energy sector.[26]
2	A review of the literature on biofuels and food security at a local level	Locke, A. and Henley, G., 2013	This literature review shows, that biofuel projects in developing countries do not necessarily worsen local food security. There is little to suggest, that the opportunities and risks of biofuel feedstock investments, differ from investments made in other commercial crops. However, activities associated with all agricultural projects bring risks that need to be acknowledged and managed. More important than the crop itself, are the way land is made available for projects, the models of production used and the project design. The use of existing safeguards and best practice in project design and land acquisition is crucial to avoid negative outcomes.	Link here[27]
3	Analyzing the effect of biofuel expansion on land use in major producing coun-	Langeveld, J. et al., 2013	This review studies biofuel expansion between 2000 and 2010 in Brazil, the USA, Indonesia, Malaysia, China, Mozambique, South Africa plus 27 EU member states. In 2010, these countries produced 86 billion litres of ethanol and 15 billion litres of biodiesel. Land use increased by 25 Mha, of which 11 Mha is associated with co-products, i.e. by-products of biofuel production processes used as animal feed. In the decade up to 2010, agricultural land decreased by 9 Mha overall. It expanded by 22 Mha in Brazil, Indonesia, Malaysia, and Mozambique, some 31 Mha was lost in the USA, the EU, and South Africa due to urbanization, expansion of infrastructure, conversion into nature, and land abandonment. In-	in: Biofuels, bioproducts & biorefining (Biofpr),

[26] https://ec.europa.eu/energy/en/topics/renewable-energy/progress-reports
[27] https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/8869.pdf.

	tries: evidence of increased multiple cropping		creases in cropping intensity accounted for 42 Mha of additional harvested area. Together with increased co-product availability for animal feed, this was sufficient to increase the net harvested area (NHA, crop area harvested for food, feed, and fiber markets) in the study countries by 19 Mha. Thus, despite substantial expansion of biofuel production, more land has become available for non-fuel applications. Biofuel crop areas and NHA increased in most countries including the USA and Brazil. To conclude, biofuel expansion in 2000–2010 is not associated with a decline in the NHA available for food crop production.	12 August 2013[28]
4	Renewables 213, Global Status Report	Randhawa, K. and Rhaman P., 2014	Market and industry trends are given together with a separate overview chapter on bioenergy. There is also a dedicated chapter on the policy landscape. Most policies to support renewable energy target the power sector, with feed-in tariffs (FITs) and renewable portfolio standards (RPSs) used most frequently. During 2012, FIT policies were enacted in five countries, all in Africa and the Middle East; the majority of FIT-related changes involved reduced support. New RPS policies were enacted in two countries. An increasing number of countries turned to public competitive bidding, or tendering, to deploy renewables. Biofuel blend mandates were identified at the national level in 27 countries and in 27 states/ provinces. Despite increasing pressure in major markets such as Europe and the United States, due to growing debate over the overall sustainability of first generation biofuels, regulatory policies promoting the use of biofuels existed in at least 49 countries as of early 2013. At least 138 countries had renewable energy targets by the end of 2012. As of early 2013, renewable energy support policies were identified in 127 countries, more than two-thirds of which are developing countries or emerging economies. The rate of adoption of new policies and targets has remained slow relative to the early/mid 2000s. As the sector has matured, revisions to existing policies have become increasingly common.	Link here[29]
5	Large industrial users of energy biomass	Vakillainen, E. et al., 2013	The objective of the study is to obtain a global overview of the biomass use in industrial and transport sectors and to compose lists of the largest users of energy biomass in the world. Various statistics, databases, reports, and reviews, most of them publicly available, have been utilised during the study to examine plants that either refine biomass for use in transportation and heating purposes or plants that convert biomass into heat and power. The plant lists presented are based on the prevailing situation at the end of 2012.	Link here[30]
6	Global Biofuels: Key to	Wright, B., 2014	The paper explains the price jumps in the grain market. Since 2005 they can be explained by new policies causing a sustained surge in demand for biofuels. The resulting reduction in available per capita	Link here[31]

[28] http://onlinelibrary.wiley.com/doi/10.1002/bbb.1432/abstract
[29] http://www.ren21.net/wp-content/uploads/2016/06/GSR_2016_Full_Report_REN21.pdf
[30] http://www.nachhaltigwirtschaften.at/publikationen/view.html/id1175
[31] https://www.aeaweb.org/articles?id=10.1257/jep.28.1.73

	the Puzzle of Grain Market Behavior		supply of food and animal feed could not be accommodated by drawing on available stocks, as they had in the past when there were temporary shortages created by yield shocks. Instead, the necessary adjustments included an expansion of global net acres planted with grains, especially in Latin America and the former Soviet Union, and by reduced per capita consumption of grains and products from animals fed on grains.	
7	Biobased fuel spurs high-flying hopes	European Biotechnology, 2015	The paper summarizes the different jet fuel technologies, its players and mentions, that further development is hindered by low fossil fuel prices and lack of policies. It also highlights several European policies and initiatives. For instance, the European Commission has carved out a possible route for overcoming the limitations, mentioned in aviation initiatives and roadmaps that defines clear milestones for achieving annual production of two million tonnes of sustainably produced biofuel for aviation by 2020 - about 4 % of the current EU fuel burn requirement. In the long run, the EC is aiming at a 40 % share of sustainable, low-carbon fuel in aviation by 2050.	Link here[32]
8	The Role of Biomass in a Future World without Fossil Fuels	Heinrich, E. et al., 2015	The report provides a survey of the current and future energy demands and generally describes all the renewable energy sources. An overview of current use and production of biomass is given. In addition, the future of biomass use is discussed. Biomass use for human food and animal feed has the highest priority and consumes already ca. 157 EJ/a. Grass and hay from grassland, which can hardly be exploited otherwise, contributes 60 % to the fodder for livestock or more. A future bioenergy contribution of 10 % up to about 20 % to a PEC of ca. 1200 EJ/a seems possible, mainly via combustion of conventional firewood and otherwise useless organic products, wastes and residues.	Link here[33]
9	Biokerosin und EE-Kerosin für die Luftfahrt der Zukunft – von der Theorie zu Pilotvorhaben	Müller-Langer, F. et al., 2015	Policy advise on establishing renewable kerosene as part of the German strategy on mobility and fuels is given. An overview of pilot projects in Germany and how much jet fuel is needed are also described. Moreover, the various technologies are judged based on e.g. TRL. Additionally, the projects are evaluated based on their ecologic sustainability. Apart from bio-based jetfuels, the study concentrates on CCU fuels, using renewable energy to produce kerosene from CO_2 and water via Fischer-Tropsch synthesis and other technologies. Several possible reasons hindering market entry of biokerosene are mentioned e.g. that people might have safety concerns, biomass availability and not enough security for investors on the demand side.	In German[34]

[3232] https://issuu.com/biocom/docs/2015_winter_eb_freeexcerpt_b622a9ffc8b053
[33] http://onlinelibrary.wiley.com/doi/10.1002/cite.201500056/abstract
[34] elib.dlr.de/103221

10	Bioenergy Out: Why bioenergy should not be included in the next EU Renewable Energy Directive	NOAH et al., 2015	Position paper of several NGOs claiming, that large-scale industrial bioenergy relies on a major expansion of industrial agriculture, monoculture tree plantations, and industrial logging, which deplete and pollute soils and water, destroy natural ecosystems and biodiversity, and destroy the livelihoods of many millions of people, particularly in the global South. In its support for large-scale bioenergy, the EU continues to use flawed UNFCCC greenhouse gas accounting rules, under which emissions from burning biofuels or biomass are ignored entirely. Emissions from 'land use change' and forest degradation are supposed to be accounted for by the countries where they happen - but that means that all biofuels and wood pellets imported into the EU are falsely classed as carbon neutral. Standards and certification cannot address fundamental issues: the scale of demand, and the scale of exploitation. No regulatory body exists in the EU or elsewhere which has the capacity to verify, audit and sanction bioenergy supply chains.	NGO report[35]
11	The land use change impact of biofuels consumed in the EU Quantification of area and greenhouse gas impacts	Valin et al., 2015	The current study is part of a continuous effort to improve the understanding and representation of ILUC. It aims to quantify emissions resulting from the existing EU biofuel policy up to 2020. The study therefore enables policy makers to assess the complete climate impacts associated with biofuel policies. This study has two types of outcomes: quantities of land conversion caused by additional biofuel demand and, based on this land conversion, greenhouse gas emission impacts for each of the modelled scenarios. The total land use change caused by the EU 2020 biofuel mandate is 8.8 Mha (million hectares), of which 8 Mha is new cropland and the remaining 0.8 Mha consists of short rotation plantations on existing cropland. From the 8.8 Mha, 2.9 Mha of conver-sion takes place in Europe by less land abandonment and 2.1 Mha of land is converted in Southeast Asia under pressure from oil palm plantation expansion, half of which occurs at the expense of tropical forest and peatland. The above-mentioned 8.8 Mha is 0.6 % of the total global crop area in 2012 of 1,395 Mha (FAO). This is around 4 % of the total land area of Indonesia, or equal to the total land area of Austria.	Impact assessment issued by the EC[36]
12	Reconciling food security and bioenergy: priorities for action	Kline, K. et al, 2016	The paper uses sustainability guidelines to create synergies between bioenergy and food security. It names the following priorities to achieve this: clarifying communications with clear and consistent terms; recognizing that food and bioenergy need not compete for land and, instead, should be integrated to improve resource management; investing in technology, rural extension, and innovations to build capacity and infrastructure; promoting stable prices that incentivize local production; adopting flex crops that can provide food along with other products and services to society, and engaging stakeholders to identify and assess specific opportunities for biofuels to improve food security.	Measures to tackle food vs. fuel debate[37]

35 http://www.biofuelwatch.org.uk/files/EU-Bioenergy-Briefing2.pdf
36 https://ec.europa.eu/energy/sites/ener/files/documents/globiom_complimentary_2016_published.pdf
37 http://onlinelibrary.wiley.com/doi/10.1111/gcbb.12366/full

13	Joint Action Plan for Smart CO2 Transformation in Europe (JAP)	Armstrong, K., et al. 2016 (SCOT consortium)	The second final SCOT document offers a joint action plan based on the R&I Agenda and gives several ideas how to overcome hurdles in the market. Concerning synthetic fuels, it claims, that most CO_2 derived fuels are not competitive with fossil fuels, similar to biofuels, so legislative action to create a market driver will be required to increase the deployment in this part of the CO_2 utilisation sector. It also says, that the European Parliament made an important step towards recognizing the benefits of CO_2-derived fuels by passing the Directive to reduce indirect land use change for biofuels, the so-called "ILUC Directive". The amendment has had an effect on the Renewable Energy Directive (2009/28; RED) and the Fuel Quality Directive (2009/30; FQD), the two main policy levers by which the business case of CO_2-derived fuels are affected. The RED mandates, that by 2020 at least 10% of EU transport fuels come from renewable sources. The FQD defines the renewable content of fuels and covers many facets of fuel production. The 'ILUC' Directive puts in place extra incentives for the use of CO_2 as a feedstock for transport fuels as advanced renewable fuels are counted double towards the 2020 target of 10 % for renewable energy use target in transport, giving it a higher market value.	Link here[38]
14	A Strategic European Research and Innovation Agenda for Smart CO2 Transformation in Europe (SERIA)	Wilson, G., et al. 2016 (SCOT consortium)	The document provides an agenda for the integration of CO_2 transformation technologies (Carbon dioxide utilization) to the European research and innovation agenda. As one of the final papers of the SCOT project (Smart CO2 Transformation), that focused on accelerating the market development of carbon dioxide utilization, the use of CO_2 was the focus. One of the main areas of CO_2 utilization is the production of synthetic fuels using industrial off-gases. Here, these technologies directly compete with biofuels. Nonetheless, SCOT also sees synergies with the bio-based economy. The Report concludes with plans to create a Joint Technology Initiative (JTI), that should act in collaboration with existing initiatives to create synergies. It will deliver significant opportunities for the European industry, including the JU BBI, to offer a greater support to the European transition towards a circular economy.	Link here[39]
15	Woody Biomass for Power and Heat: Impacts on the Global Climate	Brack, D. (Chatham House), 2017	This paper provides an overview of the debate around the impact of wood energy on the global climate, and aims to reach conclusions for policymakers on the appropriate way forward. To improve sustainability, for example, one option would be for the greenhouse gas element to be underpinned by a comprehensive life-cycle analysis for each type of feedstock, including changes in the forest carbon stock alongside supply-chain emissions. However, this is a complex calculation depending partly on the counterfactual (what would have happened to the wood, and the forest from which it was sourced, if it had	This paper is not without its opponents (see paper below)[40]

[38] http://www.greenwin.be/fr/documents/file/261
[39] http://www.greenwin.be/fr/documents/file/262
[40] https://www.chathamhouse.org/publication/woody-biomass-power-and-heat-impacts-global-climate

			not been used for energy?) and difficult to implement in real life. To account for biomass carbon emission they suggest: Forest-management reference levels should contain detailed information on projected emissions from using biomass for energy, the origins of that biomass (additional domestic forest harvests or increased use of domestic forestry residues) and the resulting emissions. The most important policy recommendation seems to be that only mill residues and post-consumer waste should receive subsidies because only these feedstocks can be assumed with confidence to reduce net carbon emissions in the short term (and even then only if there is no likelihood of diverting them from competing uses).	The same link also has a written response by Brack to paper number 16
16	Over 125 academics join IEA Bioenergy urging Chatham House to reconsider flawed policy recommendations	IEA Bioenergy, 2017	In contrast to paper number 15, IEA seems to be more favorable when it comes to the question whether wood-based energy can alleviate climate change and criticize Chatham house policy recommendations. The PR addresses three points: Firstly, the report gives an inaccurate interpretation of the impact of harvesting on forest carbon stock, proposes a misguided focus on short-term carbon balances and overstates the climate change mitigation value of unharvested forests. Secondly, the report considers roundwood to be the main woody bioenergy feedstock, but the on-ground reality is that in the EU, by-products and residues from silviculture are the most common type of feedstock. Thirdly, the report fails to acknowledge that forest bioenergy is not a single entity but an integral part of the forest management, forestry and energy-industry system that also produces material products.	This paper directly refers to the publication above (number 15)[41]

[41] https://bioenergyinternational.com/opinion-commentary/academics-iea-expertise-urge-chatham-house-reconsider-flawed-policy-recommendations

3.9.1 Key findings of the assessed studies

Our review of the literature concerning bioenergy/-fuels revealed four main topical areas. The majority of papers focused on the food vs. fuel debate and (indirect) land use change (ILUC) issues. Depending on the publication, various standpoints and interpretations of primary research data are given. We dedicated a separate chapter to CCU because it might provide a solution to the fuel vs. food dilemma. In addition, we highlighted the recent developments in aviation fuels and the ongoing debate on the question whether wood-based energy can really help with climate protection.

3.9.1.1 Bioenergy and the fuel vs. food debate

Within this assortment of texts on food vs feed, one can further differentiate between work on measuring e.g. ILUC such as Valin (2016) who aims to quantify emissions resulting from the existing EU biofuel policy to assess the complete climate impacts associated with biofuel policies (Figure 20). The study mentions:

> „The total land use change caused by the EU 2020 biofuel mandate is 8.8 Mha (million hectares), of which 8 Mha is new cropland and the remaining 0.8 Mha consists of short rotation plantations on existing cropland. From the 8.8 Mha, 2.9 Mha of conversion takes place in Europe by less land abandonment and 2.1 Mha of land is converted in Southeast Asia under pressure from oil palm plantation expansion, half of which occurs at the expense of tropical forest and peatland. The abovementioned 8.8 Mha is 0.6 % of the total global crop area in 2012 of 1,395 Mha (FAO)".

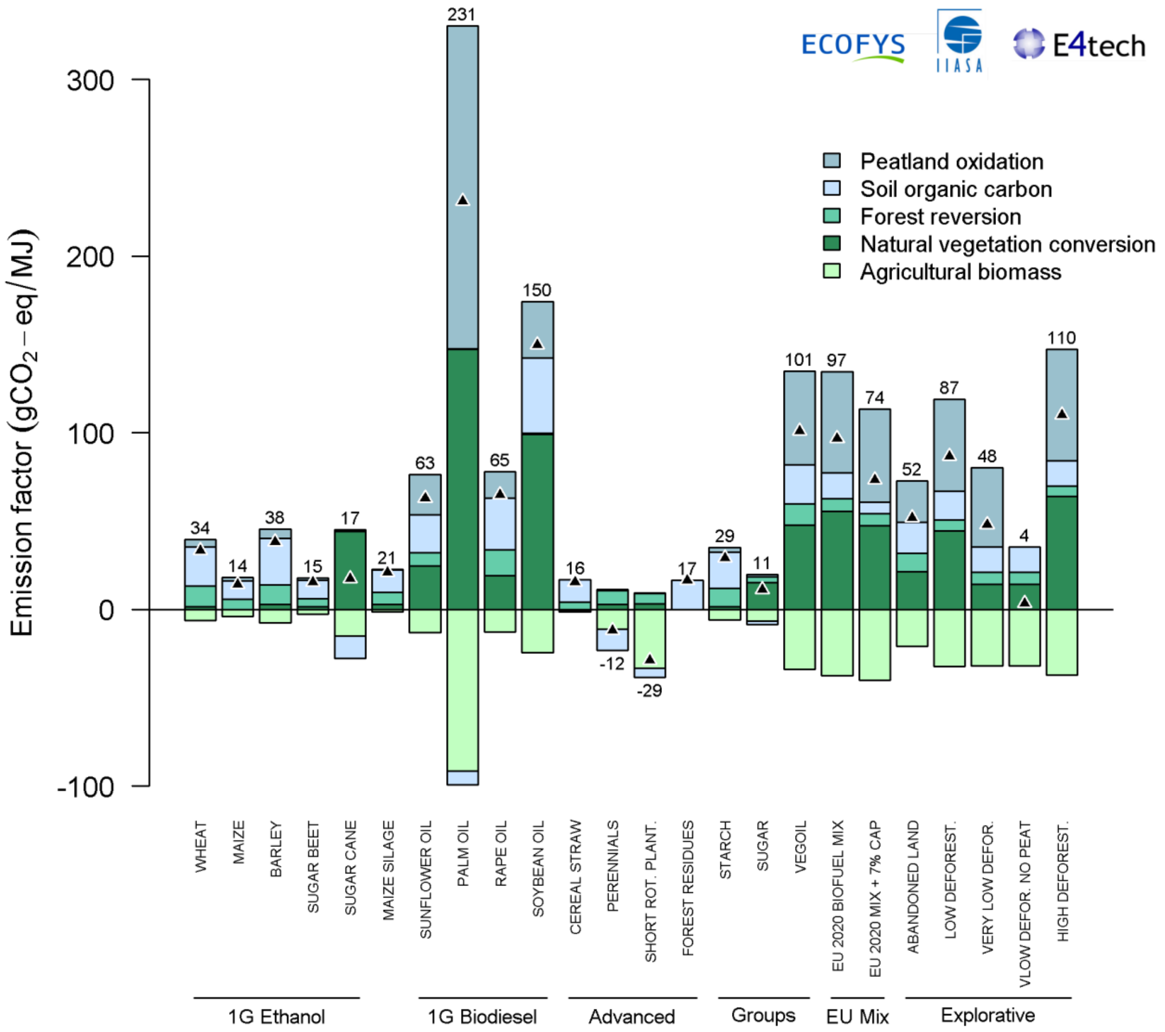


Figure 20: Overview of modelling results: LUC emissions per scenario
Source: Valin, 2016

Another paper focussing on generating primary data is Heinrich (2015). It gives data on current and future biomass consumption (Figure 21). The paper estimates that a future bioenergy contribution of 10% up to about 20% to a primary energy consumption (PEC) of ca. 1200 EJ/a seems possible, mainly via combustion of conventional firewood and otherwise useless organic products, wastes and residues.

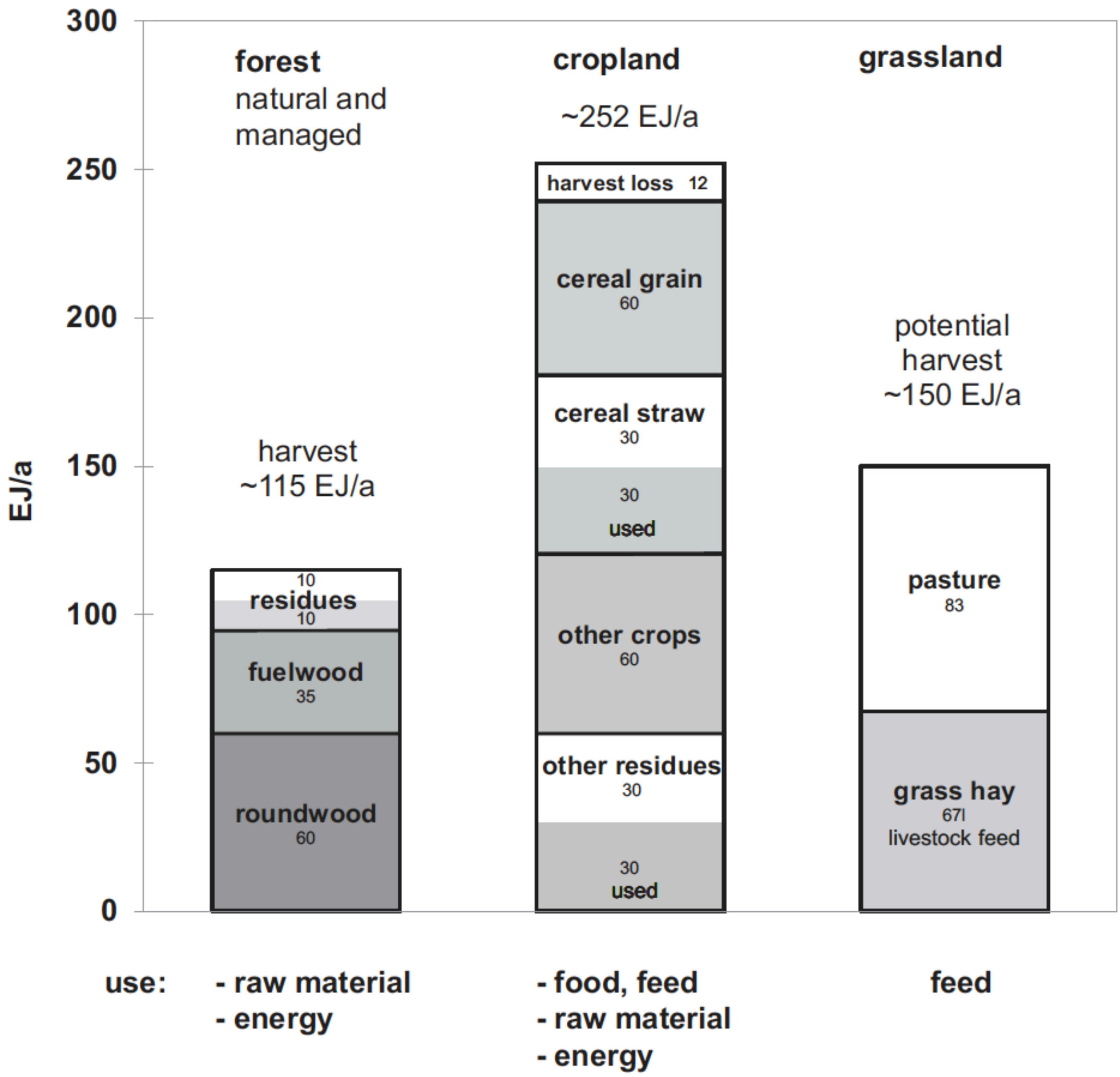


Figure 21: Estimates of sustainable future biomass harvests in EJ/a, without energy plantations by 2100.
Source: Heinrich, 2015

A position paper of several NGOs (NOAH, 2015) summarizes the main arguments of bioenergy opponents. NOAH states that bioenergy causes a major expansion of industrial agriculture, monoculture tree plantations, and industrial logging, which deplete and pollute soils and water, destroy natural ecosystems and biodiversity, and destroy the livelihoods of many millions of people, particularly in the global South.

In contrast, a literature review on these issues by Locke (2013) suggests that biofuels do not automatically worsen e.g. food security in developing countries. The report found no evidence that investing into biofuel feedstock differs in any way from the risks and opportunities of regular commercial crops. What makes the difference whether the scenarios described by NOAH (2015) become a reality, is how biofuel feedstock production is organized and how the land is made available in the beginning. Langeveld et al. (2013) confirm Locke's evaluation with their study on the effects of the increased cultivation of bioenergy crops between 2000 and 2010 in major producing countries. They found that the net harvested area for food crops was not reduced by the increase in biofuel production. It needs to be kept in

mind that these studies do not address a potential scenario in which all fuel consumption is completely covered by biofuels. Most of the discussion around food vs. fuel originated from the debate triggered by the food crisis in 2008 and therefore do not tackle the issue of complete replacement of fossil fuels by biofuels. As the FAO stated, "the links between biofuels and food security are multiple and complex and can occur in different ways at different geographic levels (local, national, regional, global) and time scales. Therefore, their assessment should be multi-faceted and contextualised, and an integrated, evidence-based, gender-sensitive and environmentally-sound approach is required in biofuel policy-making and investments"[42].

To suggest a possible solution to the debate Kline, 2016 proposes the following:

> „1) clarifying communications with clear and consistent terms, (2) recognizing that food and bioenergy need not compete for land and, instead, should be integrated to improve resource management, (3) investing in technology, rural extension, and innovations to build capacity and infrastructure, (4) promoting stable prices that incentivize local production, (5) adopting flex crops that can provide food along with other products and services to society, and (6) engaging stakeholders to identify and assess specific opportunities for biofuels to improve food security."

3.9.1.2 Bio-based aviation fuels

A second focus area of the reviewed papers was bio-based aviation fuels and how their deployment can/should be implemented. Various papers, e.g. the European Biotechnology publication from 2015 mention a lack of policies to implement biofuels in the aviation sector. The same paper also shows that numerous technologies exist and are awaiting their large-scale implementation. The EC developed a roadmap which defines clear milestones for achieving annual production of two million tonnes of sustainably produced biofuel for aviation by 2020. This is about 4 % of the current EU fuel burn requirement. In the long run, the EC is aiming at a 40 % sustainable, low-carbon fuel share in aviation by 2050. The new REDII proposal by the European Commission for the first time provides a binding policy framework for bio-based aviation fuels – it needs to be seen whether this will end up in the final Directive and whether it will have significant impacts, if it does.

[42] FAO Committee on World Food Security Report – http://www.fao.org/docrep/meeting/029/mi744e.pdf.

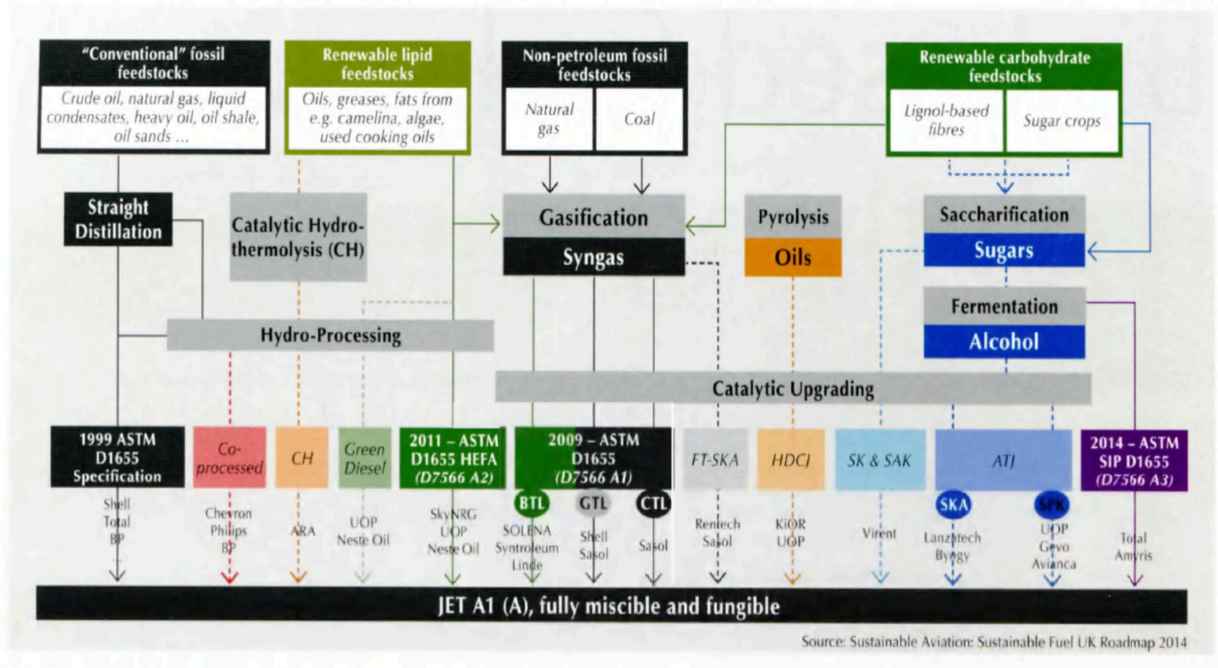


Figure 22: Overview of existing jet fuel technologies.
Source: European Biotechnology, 2015

3.9.1.3 CCU as solution to the food vs. fuel debate

Carbon Capture and Utilization (CCU) might be a possible solution to the whole food vs. fuel debate, which is why we included several papers in our overview and analysis on bioenergy/-fuel. Armstrong (2016) states that CO_2-based fuels are not competitive yet and policies need to be established to create a market driver. Therefore, the situation can be considered similar to the non-competitive biofuels. One of these drivers could be the ILUC Directive, passed by the European Parliament to reduce indirect land use change for biofuels. The ILUC Directive puts in place extra incentives for the use of CO_2 as a feedstock for transport fuels as advanced renewable fuels are counted double towards the 2020 target of 10 % for renewable energy use target in transport, giving it a higher market value. The new REDII Commission proposal also contains measures that would prolong political support for the time after 2020. Implementation needs to waited for. Müller-Lange (2015) describes various technologies to produce jet fuels, amongst them also several CCU production routes to kerosene. At the moment, market entry is hindered by, amongst others, people having safety concerns and investment risks associated with the uncertainty surrounding CO_2-jet fuels.

3.9.1.4 Can wood-based energy really contribute to climate protection?

Based on our survey, we noticed the heated discussion and numerous papers on this topic. To exemplify we chose to highlight the following two papers, because they, in turn, reference several other studies on this question. Brack (2017) from Chatham House wrote on the impact of wood energy on global climate and made several recommendations for policy makers. For instance, to account for biomass carbon emission they suggest:

> "Forest-management reference levels should contain detailed information on projected emissions from using biomass for energy, the origins of that biomass (additional domestic forest harvests or increased use of domestic forestry residues) and the resulting emissions."

To improve sustainability, the author suggests that the calculation / default values of greenhouse gas emissions should be backed up by a comprehensive life-cycle analysis for each type of feedstock, including changes in the forest carbon stock alongside supply-chain emissions. To summarize Brack, this publication is generally more cautious than the IEA when evaluating the effect of wood-based energy. Brack stresses that harvesting trees for bioenergy, to the extent as it is incentivised by bioenergy policy, will generally be counterproductive from a climate perspective and that therefore the common practice of subsidising wood-based energy in several countries in the EU should be re-evaluated. Moreover, accounting for feedstock origins, decay rates and competing uses are key to determining the likely climate impacts of its use for bioenergy.

IEA Bioenergy together with 125 scientists directly responded to Brack's work to criticize the Chatham house policy recommendations and their assumptions. The main points criticised by IEA Bioenergy (2017) were that the Brack report gives an

> "inaccurate interpretation of the impact of harvesting on forest carbon stock, proposes a misguided focus on short-term carbon balances and overstates the climate change mitigation value of unharvested forests."

They go on to say that forest bioenergy should not be considered on its own but as part of the bigger picture of forestry and its management and an energy-industry system that also produces materials. IEA Bioenergy also notes that, in contrast to the roundwood which the Brack report bases its assumptions on, reality in the EU looks different. According to them, residues and by-products of silviculture are the most commonly used feedstock for wood-based bioenergy. To conclude, IEA Bioenergy is more sanguine in their assessment of the risks and uncertainties associated with biomass for heat and power, for example regarding the implications of short-term carbon fluxes for climate tipping points; the credibility of assumptions regarding how bioenergy demand affects forest growth; and the ability of sustainability schemes and chains of custody to ensure favourable outcomes.

Based on nova's expertise and observation of this discussion, the final answer of this question will largely depend on how biogenic and fossil CO_2 are handled in the various studies modelling the impact on promoting wood-based energy via various policies and how the changes in forest carbon stock are accounted for.

3.9.2 Trends and emerging markets

Based on the analysed papers, the bioenergy/-fuel sector seems to be the one of the most researched and covered areas. On the technological side, jet fuels seem not to be able yet to create a technology push but still rely heavily on policies to promote their use. The food vs fuel debate remains a hot-button issue. Nonetheless, more and more scientific publications indicate that biofuels are not as detrimental to food security as is widely believed. CCU might provide an additional possible solution. Whether wood-based energy can really alleviate climate change remains to be seen, as discussions on this topic are extremely controversial at the moment. It is problematic that most of the 'evidence' heavily relies on assumptions and modelling results, which make it almost impossible to pinpoint one correct claim.

Based on the mentioned discussion it seems to be reasonable to assume that the growth of the biofuel/-bioenergy share in the EU energy mix will heavily depend on the degree of subsidies they might receive. This high degree of uncertainty might hinder the further development of the bioenergy sector, because this translates into lack of security for investors. The heated comments on the Commission REDII proposal from November 2016 issued by

different industry associations testifies to this fact. Another factor might be that valuable, renewable alternatives to biomass-derived energy exist and that technological advances make the material use of biomass more economically attractive for an increasing number of feedstocks compared to simply burning it or converting it to fuel.

3.9.3 Discussion and identification of gaps

Compared to other sections of our report, the most research seems to have happened in the area of bioenergy/-fuel. Therefore, we could not identify any remaining gaps apart from the uncertainties regarding assumptions and statements mentioned in the conclusion.

4 Socio-economic aspects

4.1 Employment, turnover, GDP

Table 19: Studies relevant to employment and turnover effects of bioeconomy

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	Employment and value added – A Comparison between the European Pulp and Paper Industry and the Bioenergy Sector	CEPI, 2011	The purpose of this study was to analyse direct and indirect value added and employment in the European pulp, paper and paperboard industry for the year 2008. Moreover, an alternative use of wood and recovered paper was studied, calculating the corresponding estimates for the bioenergy sector assuming that the same raw materials would be used to produce energy. The study concludes that in 2008, the value added in the pulp, paper and paperboard industry was around 19.7 billion €. An additional 20.6 billion € were created in upstream activities and 56.8 billion € in downstream alternatives, coming to a total of 97.1 billion € in value added. Also, the number of employees was estimated in 208,200 in the pulp, paper and paperboard industry, at 337,300 in upstream and 1,051,700 in downstream activities, coming to a total of 1,597,200 employees directly and indirectly working for this industry. The comparison to a theoretical energetic usage of the same amount of biomass concludes that the use in material industries creates much more value added and employment than the energy use could.	Out of scope timewise, but important study[43]

[43] http://www.cepi.org/system/files/public/documents/publications/forest/2012/FOR-142-11final.pdf

2	Bio-based Economy in the EU-27: A first quantitative assessment of biomass use in the EU industry	Carus, M., 2012	This paper presents the first ever collection and analysis of data on the bioeconomy at an EU-27 level. It gives a rough overview of the quantitative dimensions of Europe's bio-based economy with a focus on industrial material use of biomass. The paper is divided into three parts: The first section explains the methodology and definitions that constitute the basis of the research and a short review of existing literature. This is then followed by a depiction of market data of the bio-based sector. EUROSTAT data was used to calculate the volume of biomass flows that are used industrially as well as the different macroeconomic effects generated by several bio-based industries. The calculation of macroeconomic effects includes indicators such as number of enterprises, employed persons and value added.	Contribution to the Commission's Impact Assessment in 2012 (not publicly available) *This is the first assessment of these effects by nova-Institute. The method was refined and updated in later publications (latest edition in this study).*
3	Volkswirtschaftliche Bedeutung der biobasierten Wirtschaft in Deutschland	Efken, J. et al., 2012	Assesses the macroeconomic impact of the bio-based economy in Germany for the year 2007, based on the following indicators: number of companies, employment, turnover and gross value added. Altogether, five million employees, representing 12.5 % of all employees and 165 billion Euros, representing 7.6 % of German gross national product have been calculated as the share of biobased economy in Germany. Challenges, still not finally solved are that neither the available data nor the economic activities themselves can be unambiguously assigned to bioeconomy or "non-bioeconomy"	Available in German only[44]
4	Study on: Methodology framework for the bioeconomy observatory	Dammer, L., Piotrowski, S., Carus, M. 2014	Study does not contain data on socio-economic benefits itself, but provides a comprehensive overview and analysis of the current statistical framework in Europe that would (or would not) enable a monitoring of these effects. The study assesses existing databases and data gaps. It then proceeds to suggest different methodologies of how these data gaps could be filled. The study built the ground for parts of the bioeconomy observatory.	Study carried out by nova-Institute for the JRC – milestone for these activities in Europe see Annex V in link[45]
5	The Bioeconomy in the European Union in numbers	JRC (IPTS), 2015	Short briefing paper on biomass extraction and use as well as on turnover and employment generated by the bioeconomy in the EU. The European bioeconomy generates a turnover estimated at around 2 trillion euros and employs more than 17 million of persons.	Data based on cooperation between JRC and nova[46]

[44] http://literatur.thuenen.de/digbib_extern/dn051397.pdf
[45] https://biobs.jrc.ec.europa.eu/sites/default/files/generated/files/documents/JRC Methodology Report Bioeconomy Observatory February 2014.pdf
[46] https://biobs.jrc.ec.europa.eu/analysis/bioeconomy-european-union-numbers

6	Monitoring a biobased economy in the Netherlands	Kwant, K., Gerlagh, T., Meesters, K., 2016	In order to gain insight into the material flows and economic impact of the bio-based economy in the Netherlands, several studies have been carried out. As a result, a protocol for monitoring biobased material flows in a biobased economy was developed and initial data about the economic impact were collected. This paper describes the protocol and monitoring results for the Netherlands. Results reveal that the application of biomass in the chemical sector result in higher economic value.	Link here[47]
7	Bioeconomy in Figures	Piotrowski, S., Carus, M., Carrez, D., 2016	Analyses turnover and employment generated by the bioeconomy and different sub-sectors for the EU-28 and its Member States for the year 2013. Finds 2.1 trillion mio € turnover and 18.3 people employed by the EU bioeconomy.	data prepared by nova for BIC[48] *updated data obtained by the same methodology provided in this study*
8	A global view of bio-based industries: benchmarking and monitoring their economic importance and future developments	Parisi, C., Ronzon, T., 2016	This report presents the conclusions of a workshop between bioeconomy stakeholders from the EU, Canada, the US and Brazil. There is a clear common interest between these countries/regions in measuring and monitoring the bioeconomy sector. A common issue is the lack of data. Report gives a good overview of the different activities going on to collect data: - nova-Institute - JRC - Renewable Raw Materials (RRM) group - CEFIC - specific FP7 projects (e.g. BIO-TIC) - Member State level: The Netherlands JRC and Wageningen UR are modelling the socio-economic impacts of the EU bioeconomy in a general equilibrium model (MAGNET) in the project SAT-BBE.	JRC Technical Report on the EU-Brazil Sector Dialogues Workshop, 18-19 February 2016, Seville, Spain[49]

[47] http://www.etaflorence.it/proceedings/?detail=11561
[48] http://biconsortium.eu/sites/biconsortium.eu/files/downloads/20160302_Bioeconomy_in_figures.pdf
[49] http://publications.jrc.ec.europa.eu/repository/bitstream/JRC103038/lb-na-28376-en-n .pdf

9	Macroeconomic outlook of sustainable energy and biorenewables innovations (MEV II)	van Meijl, H. et al., 2016	This macroeconomic assessment of large-scale deployment of biomass to 2030 shows that a bioeconomy can positively contribute to the Dutch economy, contributes to achieving the emission reduction targets and alleviates part of the cost of achieving the overall emission reduction targets. High technological change and global markets with low biomass prices are important to achieve these impacts. The economic impact is very much related to volatile fossil energy prices. Low fossil energy prices reduce the macroeconomic benefits but the contributions of the bioeconomy to emission reduction remain. To achieve the positive macroeconomic impacts and emission reduction a stimulus by policies (e.g. CO_2 taxes, R&D policies) is necessary.	Link here[50]
10	Analysis of the European Crude Tall Oil Industry – Environmental Impact, Socio-economic Value & Downstream Potential	Rajendran, V.K. et al., 2016	This study undertook a scientific, quantified and a comprehensive analysis to estimate and compare the environmental impact, the economic added value (EAV), and the social impact (direct, indirect and induced jobs) of the existing European pine chemical industry refining CTO to bio-based chemicals to that from the competing process route converting CTO into biofuel (renewable diesel). Both cases were based on the assumption that all 650,000 tonnes of the CTO available in the EU were utilised in their respective processing routes. Key findings: • Utilising CTO in the full life cycle of production, use and disposal of industrial and consumer chemicals produces **slightly lower** amounts of **GHG** emissions compared to using the same amount of CTO in the production and consumption of renewable diesel. • The **EAV** generated by the entire pine chemicals is at least **4 times more** than the added value generated from the production of renewable diesel. The total economic added value generated by pine chemicals was estimated to be around 1,800 million €, whereas the renewable diesel would have generated only 300 million € (for the base year 2015).	short name: EU CTO – Value Added Study, Fraunhofer UMSICHT[51]

[50] http://edepot.wur.nl/370901
[51] https://c.ymcdn.com/sites/www. pinechemicals.org/resource/resmgr/Studies/EU_CTO_Added_Value_ Study_Fin.pdf

			• The total **employment** generated by the pine chemicals industry and its downstream value chain is at least **20 times more** than that generated from the production of renewable diesel.	
11	Jobs and growth generated by industrial biotechnology in Europe	Debergh, P, Bilsen, V., Van de Velde, E., 2016	This study quantifies the different economic effects associated with the activities of the industrial biotechnology (IB) sector in Europe. The results show that total employment in the IB value chain amounts to about 486.000 full-time equivalents (FTEs). About 94.000 FTEs are generated in the IB sector itself, while some 269.000 FTEs are created in the upstream part of the value chain, i.e. by the suppliers of good and services to the IB sector. In addition, some 98.000 FTEs are generated downstream of the IB sector, whereas the employment of about 25.000 people is induced by the spending of employees in the earlier categories. Along the IB value chain, more than €31 billion is generated in terms of value added.	report produced for EuropaBio[52]

[52] http://edepot.wur.nl/392244

4.1.1 Key findings of the assessed studies

The socio-economic effects of bioeconomy are not very well known as a whole. There are a few sector-specific studies on the wood processing and the pine chemicals industries (CEPI 201, Rajendran et al. 2016) or on the Industrial Biotechnology sector (Debergh et al. 2016) in Europe. The other studies looking at bioeconomy as a whole are either focused on a certain member state (so far, Germany and the Netherlands are the only countries where such studies could be found, cf. Efken et al. 2012, Kwant et al. 2015) or on Europe (for data on other regions than the EU, please refer to the Global Trends chapter). For Europe as a whole, nova-Institute and the JRC are the only players providing data so far and they collaborate closely to offer consistent information.

All studies assessed in this report found positive contributions of bioeconomy towards value added generation and job creation in the EU. Those studies that executed a comparison between material uses and energy uses of biomass conclude clearly and unanimously that the material uses create much more value added and employment per tonnes of biomass and also in total than the energy sectors can. This is mostly due to the longer and more complex value chains of the material usages (CEPI 2011, Rajendran et al. 2016). Several studies also point out that material uses of biomass enable GHG emission savings at the same level or at even higher levels than the energetic use of biomass and could thus reduce costs of GHG abatement (Rajendran et al. 2016, van Meijl et al. 2016). None of the studies contain a calculation of GDP share of bioeconomy.

4.1.2 Discussion and gap identification

As mentioned, there is limited information on the socio-economic effects of bioeconomy in Europe. Political stakeholders are aware of this problem. The creation of the Bioeconomy Observatory (BISO) was a first step to address this lack and nova-Institute contributed by developing methodologies that could help to overcome information gaps in the existing statistical databases. Most of the gaps identified in that study (Dammer et al. 2014) still exist. A new H2020 call has been launched in order to take further steps to address this. In the meantime, nova-Institute and JRC collaborate closely to provide what data is possible to provide with the available databases. An update of these activities is provided in the framework of this report, see chapters below.

In addition to the European activities, some member states have started to collect information on the socio-economic impacts of the bioeconomy. The Netherlands is the first country which has developed a protocol for monitoring bioeconomy, and in Germany there are currently three projects working towards establishing a national bioeconomy monitoring.

None of the studies refer to the share of GDP which is created by bio-based or bioeconomy. Whether this is due to a lack of interest in this information or more due to a lack of agreed-on methodology is unclear.

4.1.3 New nova calculations: Employment and turnover

4.1.3.1 Sources and methodology

The main data source for all sectors of the bioeconomy shown in the following figures is Eurostat. For those sectors that can be fully attributed to the bioeconomy, the data on turnover and employment was directly obtained from the respective Eurostat datasets. These sectors comprise primary biomass production (agriculture, forestry and fishery) as well as the sectors food, beverages, tobacco, paper and paper products.

The sectors textiles and textile products, forest-based industry, chemicals (including enzymes) and plastics as well as pharmaceuticals only partly contain bio-based products. Therefore, the bio-based shares of these sectors need to be estimated and only these estimated shares are accounted for in the pie charts.[53]

The sector forest-based industry includes wood products, that are considered fully bio-based, but also furniture, which is only partly bio-based (based on wood and/or natural fibres).

The sectors chemicals and plastics and pharmaceuticals include a multitude of fully bio-based (e.g. natural dyes and pigments, enzymes, fatty acids) and partly bio-based products (different chemicals and plastics that are traditionally petro-based but in recent years also partly bio-based).

Currently, out of the 536 products in Division 20, 110 are fully or partly bio-based. From these 110 products, 39% are 100% bio-based (e.g. tanning extracts of vegetable origin, sorbitol, tall oil), 25% products with a bio-based share of at least 10% (e.g. ethylene glycol, carboxylic acid, adipic acid) and 36% products of lower bio-based shares (e.g. acetic acid, methanol, epoxy resins). The majority of products, 426, is therefore currently non-bio-based. For those product groups that contain partially bio-based products, a percentile share has been calculated in order to provide realistic numbers on the effects of bio-based economy. The shares have been developed and are continuously being fine-tuned in collaboration with several bio-based economy experts and nova-Institute.

Both biodiesel and bioethanol have dedicated product codes within the Eurostat production database PRODCOM. Therefore, their shares in the total production values of their respective NACE Classes were calculated and then the assumption was made that the same shares apply to employment and turnover.

In the case of bioenergy for heat and power (biogas and solid biomass), their shares in employment and turnover of total energy production have been estimated, taking into account a higher labour intensity of renewables due to the handling and more decentralised plants.

While there are other data sources available for bioenergy and biofuels (mainly the annual reports of EurObserv'ER[54]), these sources are not compatible with Eurostat since they include both direct and indirect jobs and there is no clear indication how to separate both.

The graphs provided in this study differentiate between the overall bioeconomy (incl. primary production as well as food & feed), the bioeconomy excl. food & feed as well as the narrower so-called "bio-based economy" which excludes also primary biomass production. This is a usual categorisation in order to illustrate different effects and characteristics, since

[53] Note that the percentages in the following pie charts do not always add up exactly to 100% due to rounding.

[54] http://www.eurobserv-er.org

the food market for example follows a different dynamic than the chemical industry. This way of depicting the data allows for more in-depth interpretation.

4.1.3.2 Turnover

Turnover in the EU bioeconomy (EU-28, 2008-2014)

The analysis of the Eurostat figures from 2008, 2013 and 2014 shows that the turnover of the total bioeconomy (including food and beverages and the primary sectors agriculture and forestry) in the EU28 increased continuously from 2.11 trillion EUR to 2.26 trillion EUR.[55]

Roughly half of this comes from the food and beverages sector, almost a quarter of the turnover is produced by the primary sectors (agriculture and forestry), while the other quarter is produced by the so-called bio-based industries (such as chemicals and plastics, pharmaceuticals, paper and paper products, forest-based industries, textile sector, biofuels and bioenergy). Noticeable contributor to the increase in turnover was especially the food sector.

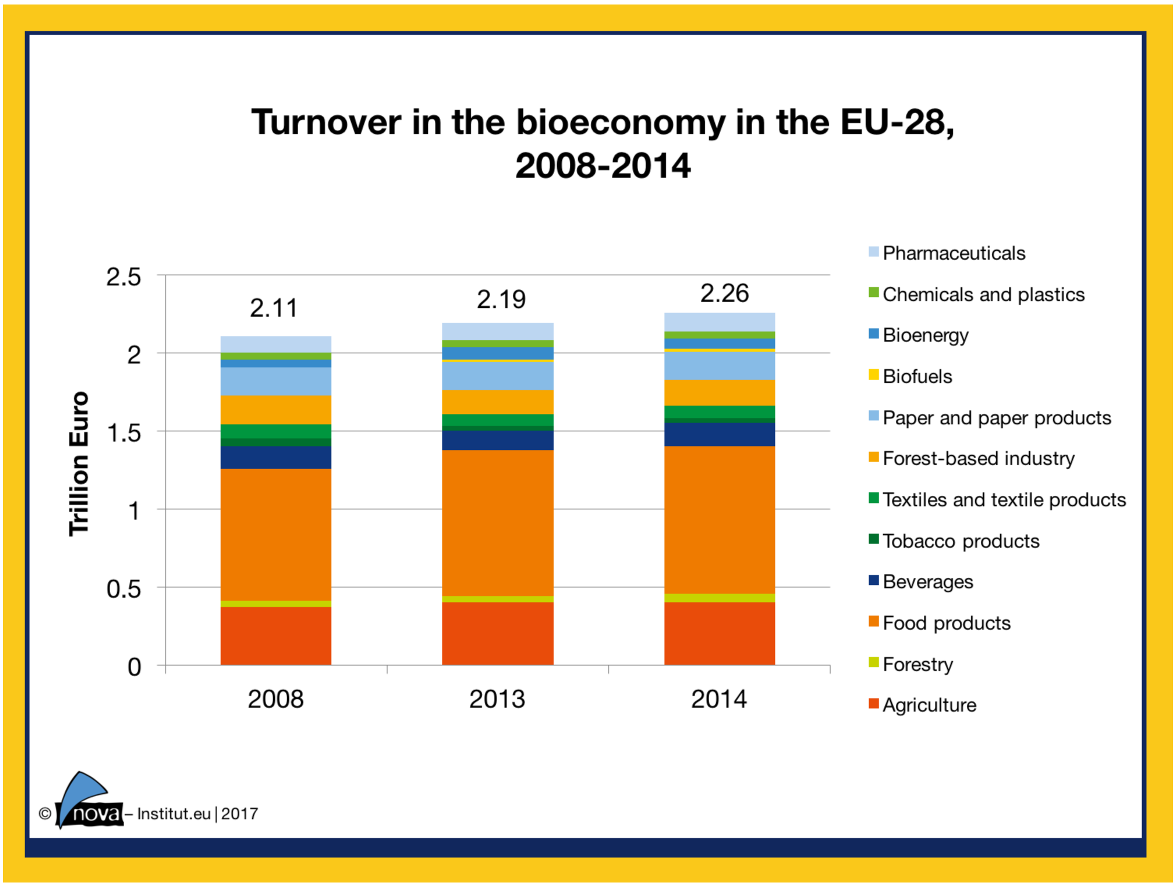


Figure 23: Turnover in the bioeconomy in the EU-28 2008-2014
Source: nova-Institute 2017, own research

[55] Note that results for 2008 and 2013 differ slightly from previous studies due to a re-evaluation of bio-based shares for the sectors chemicals and plastics and pharmaceuticals. This re-evaluation has taken place in several projects of nova-Institute, e.g. in collaboration with the Commission's JRC and EuropaBio as well as other industry experts.

Turnover in the EU bio-based sector (EU-28, 2008-2014)

If the sectors food, beverages and tobacco products are excluded, the analysis still shows an increase from 1.07 to 1.13 trillion Euro over the same period.

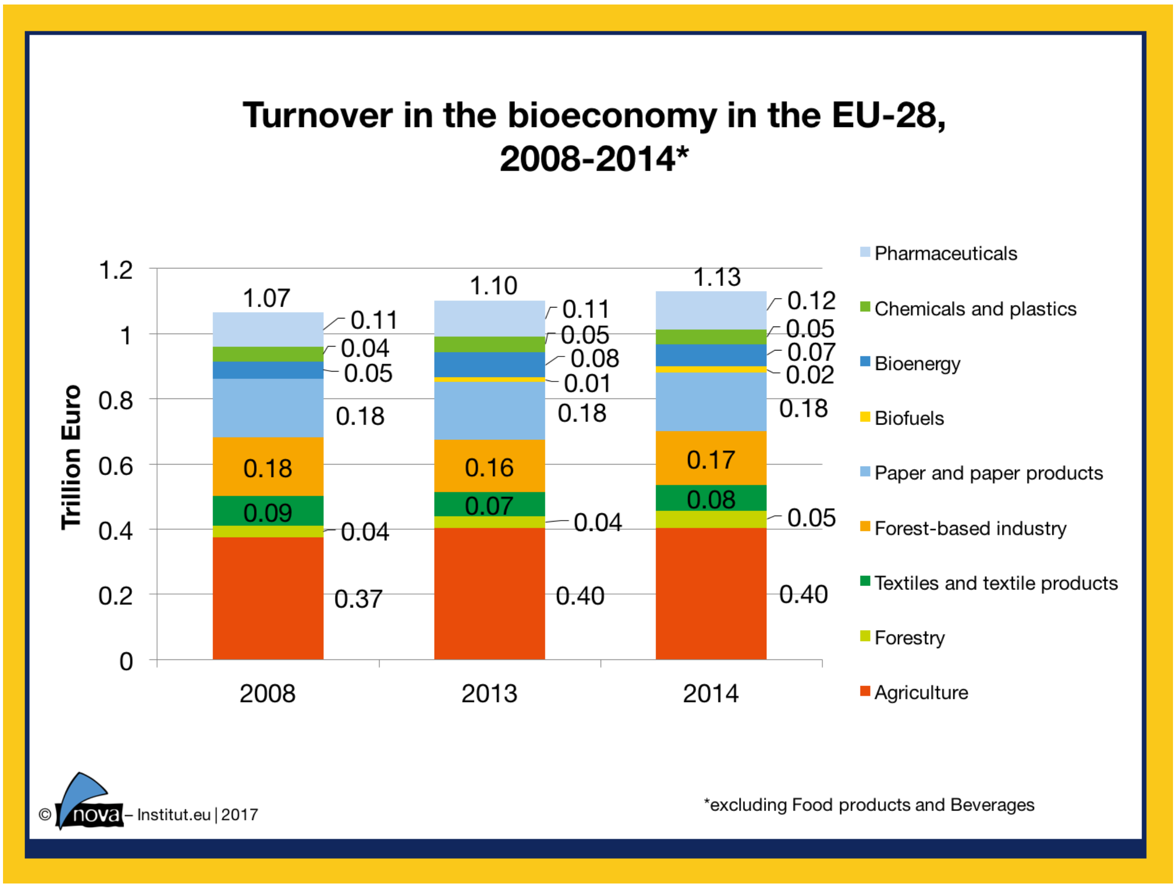


Figure 24: Turnover in the bioeconomy (excl. food, feed and tobacco) in the EU-28, 2008-2014.
Source: nova-Institute 2017, own research

When also the primary biomass production/extraction is excluded, the analysis shows that biofuels and bioenergy together accounted for roughly 13-14% of the turnover of the EU industrial sectors that are referred to as 'bio-based economy', which corresponds to a total amount of approximately 90 billion €.

The sectors paper and paper products (27%) and forest-based industry (wood products and furniture, 25%) make up for the largest shares of turnover, together this amounts to roughly 250 billion €. Bio-based chemicals accounted for 45 billion €. The total turnover of the bio-based industries reached 660 billion EUR in 2013 and 674 billion EUR in 2014. The slight decrease in the turnover of bio-based chemicals and plastics from 2013 to 2014 can be largely explained by a decrease in the overall sector, but also by potential lack of data. Since Eurostat data is filled by and by, it could be possible that the values change some more in the next few months.

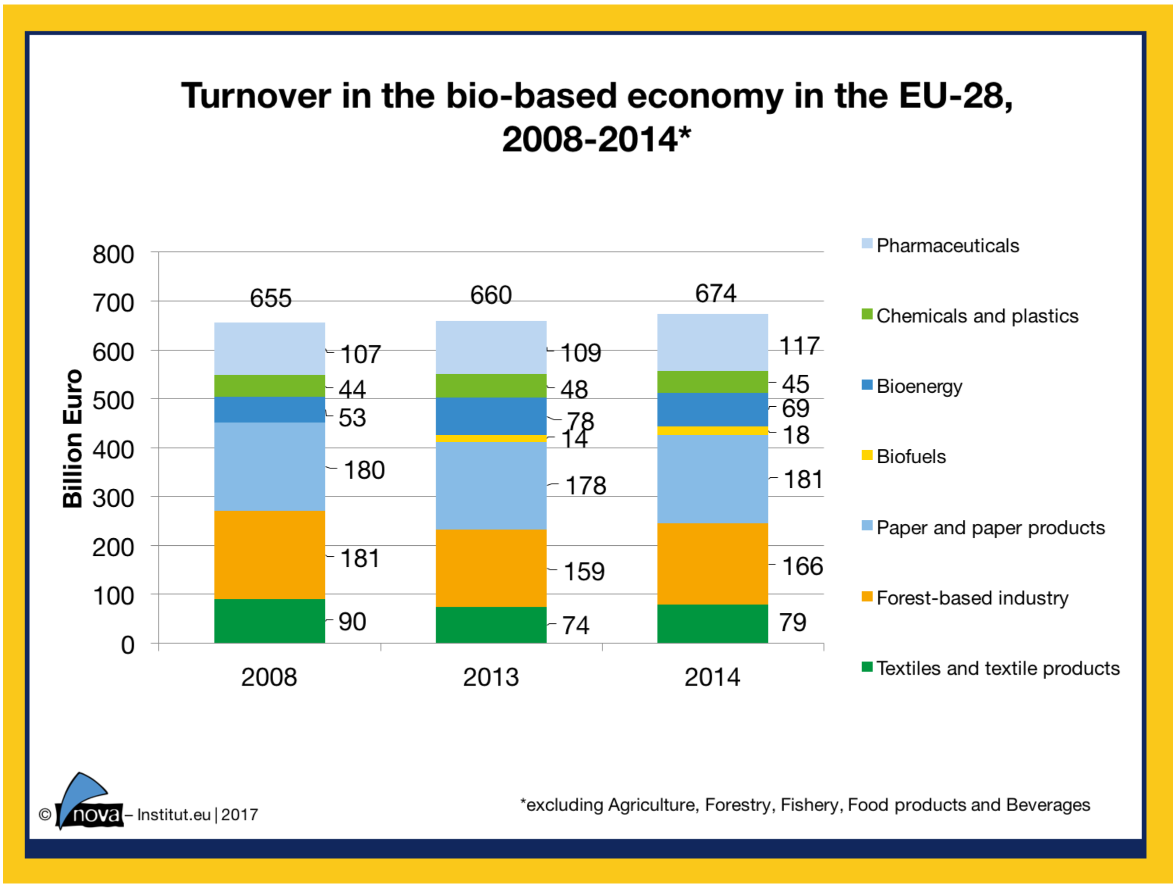


Figure 25: Turnover in the bio-based economy in the EU-28, 2008-2014
Source: nova-Institute 2017, own research

4.1.3.3 Employment

Employment in the EU bioeconomy (EU-28, 2008-2014)

This chart shows the distribution of total employment in the EU bioeconomy for the same sectors as the bar chart for total turnover, using the same methodology as for that chart. The comparison of both charts shows clearly that the primary biomass production, mainly agriculture, generates a lot of employment but low turnover.

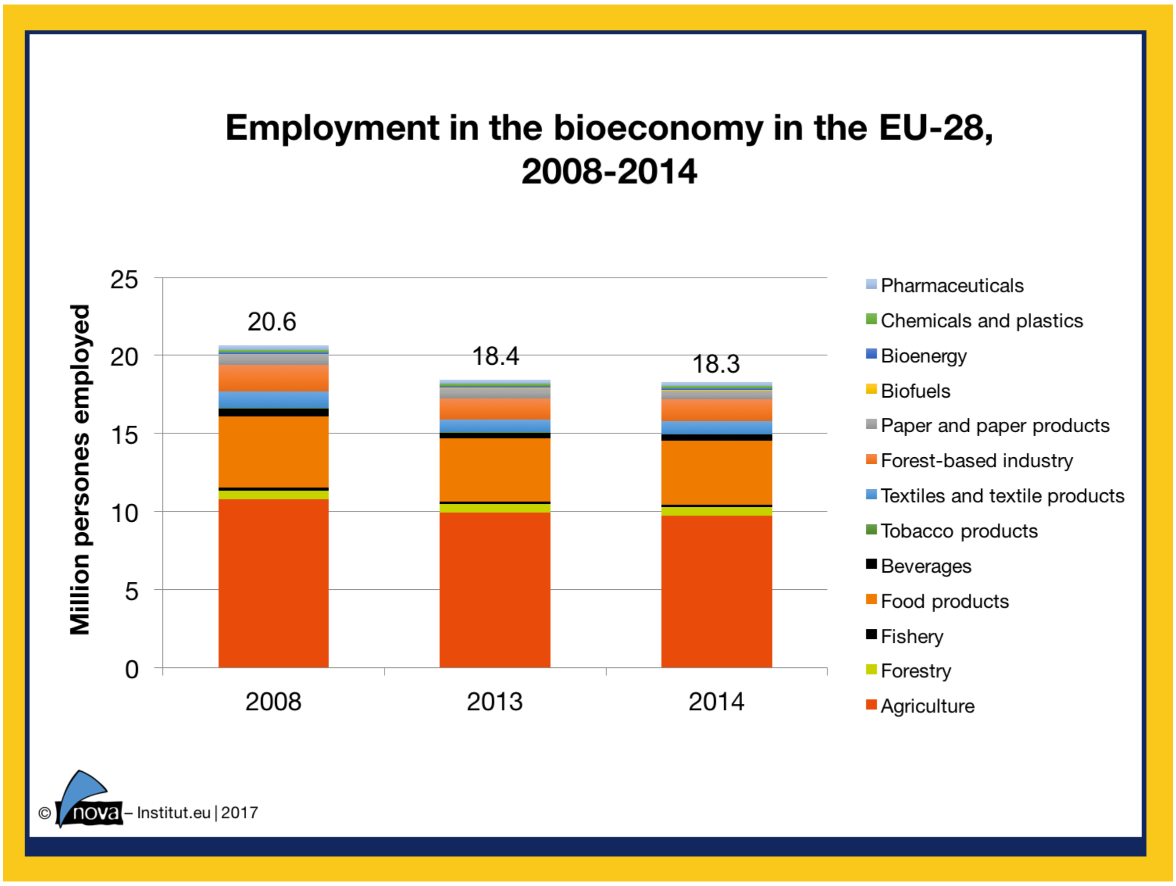


Figure 26: Employment in the bioeconomy in the EU-28, 2008-2014
Source: nova-Institute 2017, own research

Employment in the EU bio-based sector (EU-28, 2008-2014)

For this chart, the sectors food, beverages and tobacco products have been excluded. The total employment results in 13.8 million jobs (full time equivalent) with more than 3 quarters in the primary sector. There is a continuous decline in employment from 2008 to 2014, especially due to the agricultural sector.

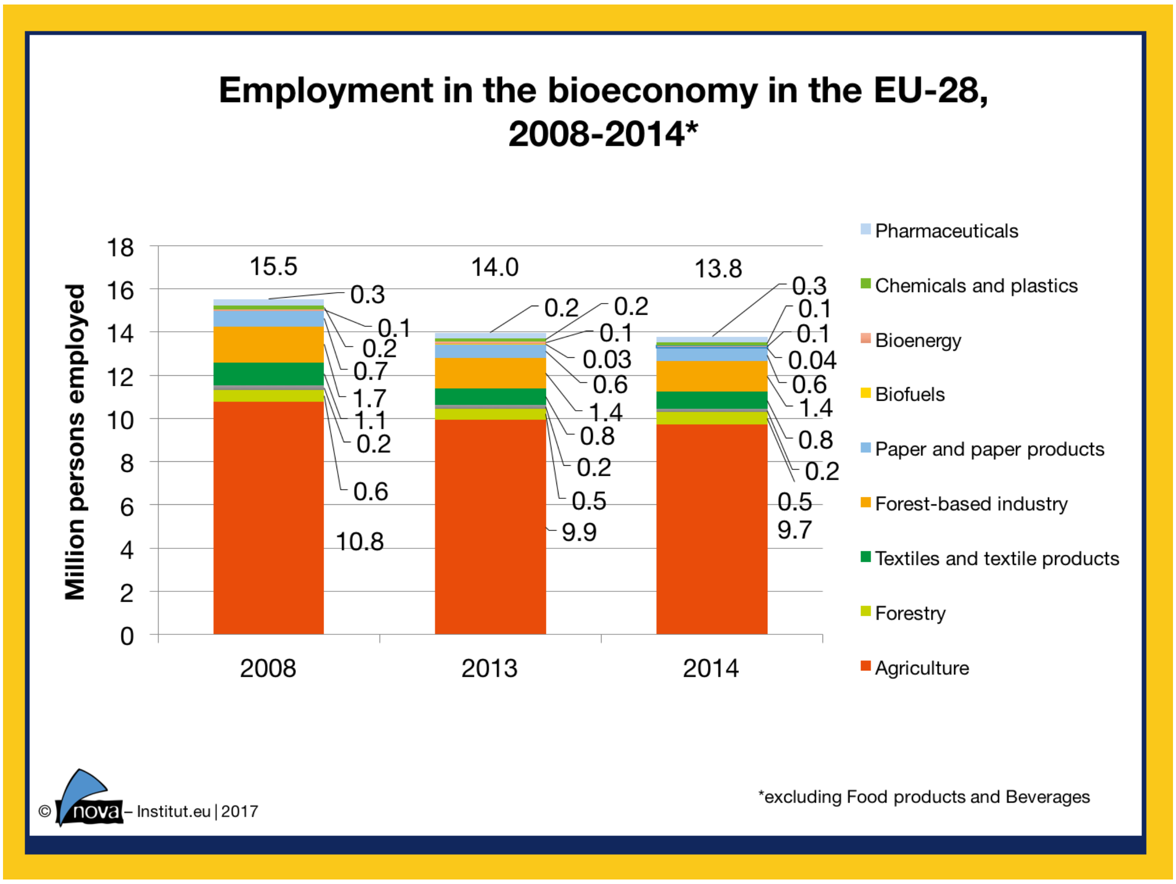


Figure 27: Employment in the bioeconomy (excl. food, feed and tobacco) in the EU-28, 2008-2014.
Source: nova-Institute 2017, own research

If only the "industrial sectors" are analysed (so excluding also the primary biomass production/extraction), the total employment is 3.3 million jobs (full time equivalents, (fte)) in 2014. The most prominent sectors are the forest-based industry, paper and paper products, and the textile industry. In the period between 2008 and 2013, there was apparently a strong decrease in the employment in the forest-based industry and the textile industry, which can be due to the overall crisis following the year 2008, and to some parts to increases in productivity.

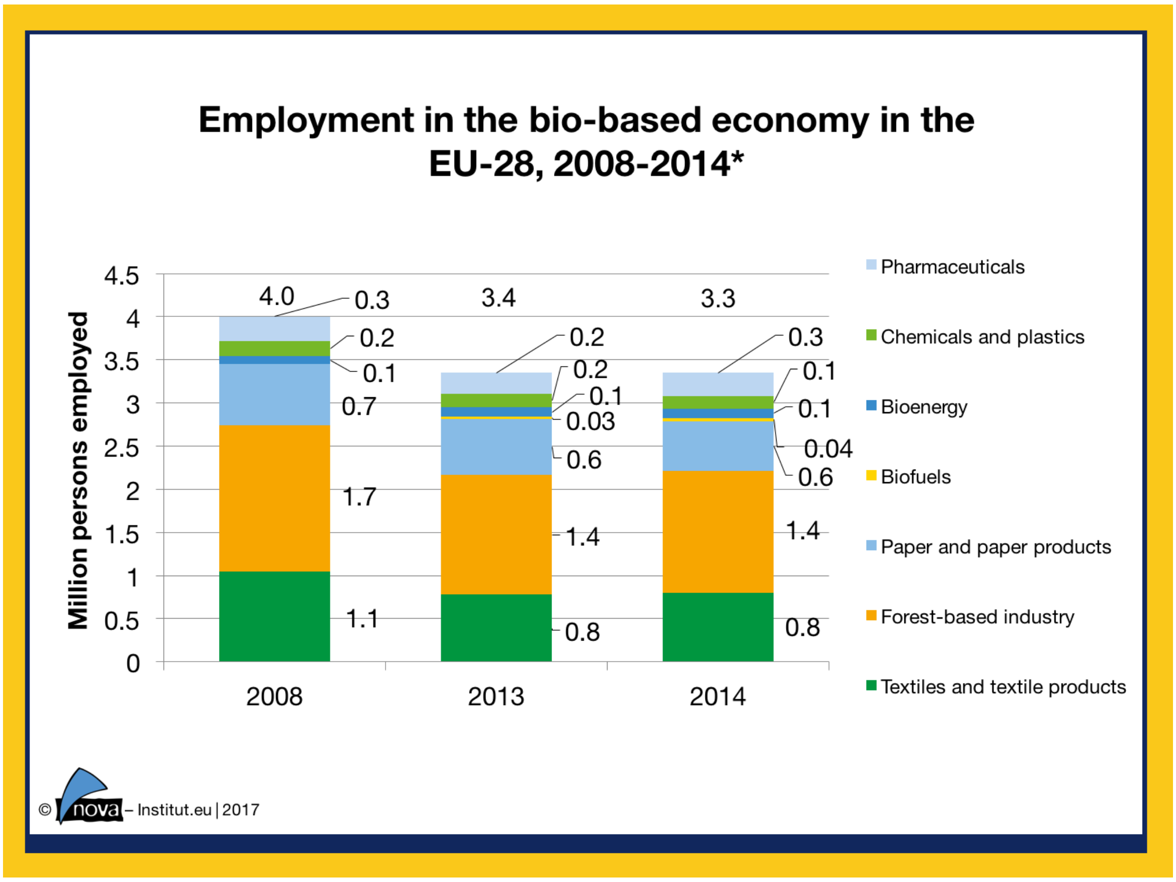


Figure 28: Employment in the bio-based economy in the EU-28, 2008-2014
Source: nova-Institute 2017, own research

4.1.3.4 Turnover and employment in the EU bio-based economy per Member State (EU-28, 2013-2014)

These two bar charts compare the total turnover and employment of the bio-based economy (excl. agriculture, forestry, fishery, food, beverages and tobacco products) for each Member State of the EU-28 in 2013 and 2014. The figure shows clear differences between groups of Member States, e.g. the Eastern European countries Poland, Romania and Bulgaria apparently are stronger in less value-added sectors of the bio-based economy that generate a lot of employment.

In comparison, Western and Northern European countries generate much higher turnover compared to the employment generated. The countries with the largest difference between turnover and employment are Ireland, Finland and Belgium.

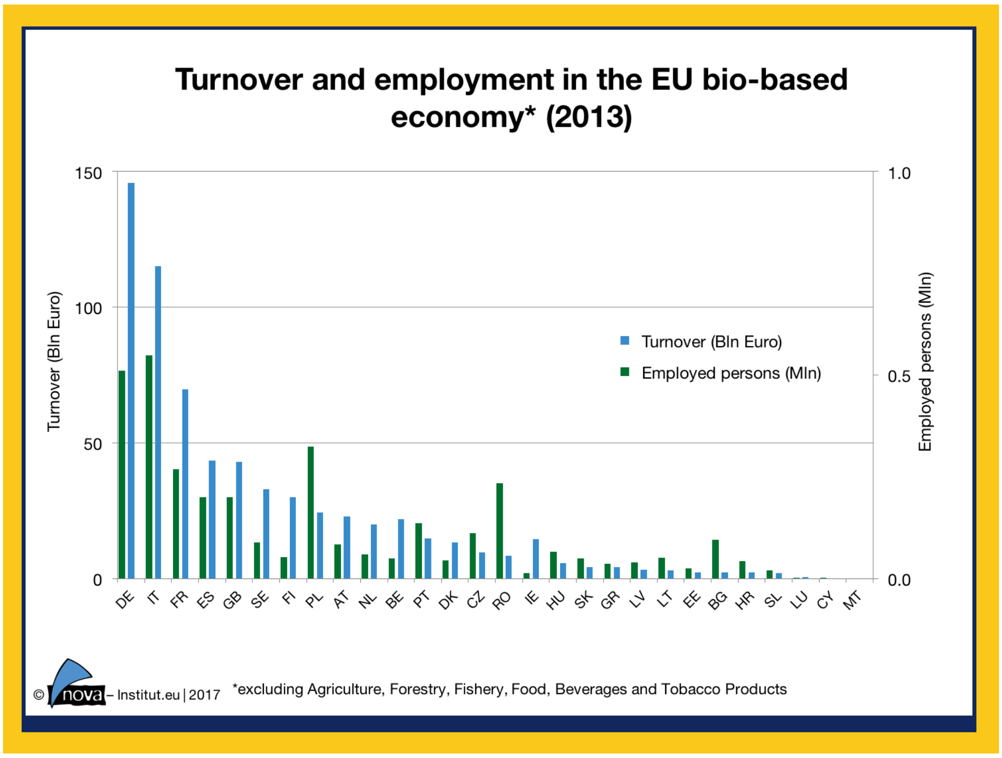


Figure 29: Turnover and employment in the EU bio-based economy per Member State 2013.
Source: nova-Institute 2017, own research

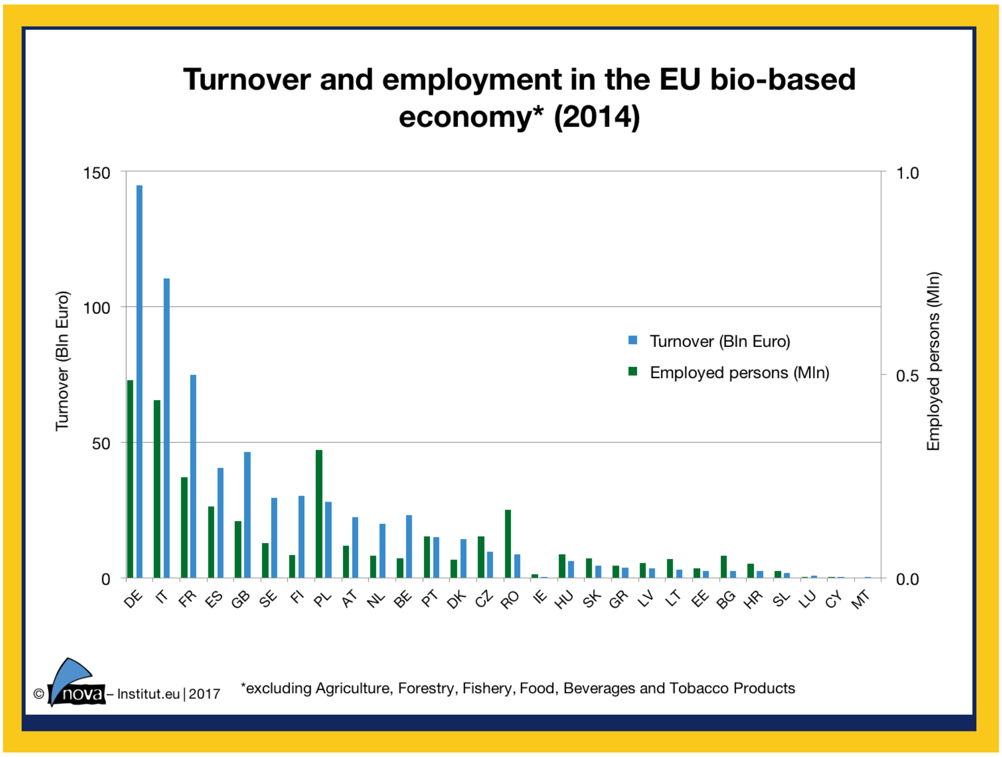


Figure 30: Turnover and employment in the EU bio-based economy per Member State 2014.
Source: nova-Institute 2017, own research

4.1.3.5 Employment per turnover in sectors of the bio-based economy (EU-28, 2008-2014)

The following figure compares the number of employed persons per 1 million Euro of generated turnover for the bio-based sectors textiles and textile products, forest-based industry (wood products and furniture), paper and paper products, chemicals and plastics, pharmaceuticals, biofuels and bioenergy over the period 2008, 2013 and 2014.

This analysis shows that bioenergy and biofuels generate relatively little employment compared to their turnover. The differences between the sectors shown in this figure can be well explained. The sectors textiles and textile products as well as forest-based industry are relatively labour intensive sectors with comparably low value added. On the other hand, the production of bioenergy and biofuel products requires relatively little labour (only a few processing steps) compared to their turnover. Note that employment and turnover here always only refer to the end product manufacturing stage, i.e. neither the employment and turnover in primary biomass production nor indirect effects in other sectors due to machinery purchases etc. is accounted for in any of the industrial sectors.

Chemicals and plastics as well as the pulp and paper sector can be found in an intermediate position. Their production requires more labour than bioenergy (more and more complex processing steps) but also generates more value added than textiles and textile products as well as forest-based industry. The overall decrease in the ratio from employment to turnover hints at improved productivity, indicating a continued competitiveness of Europe.

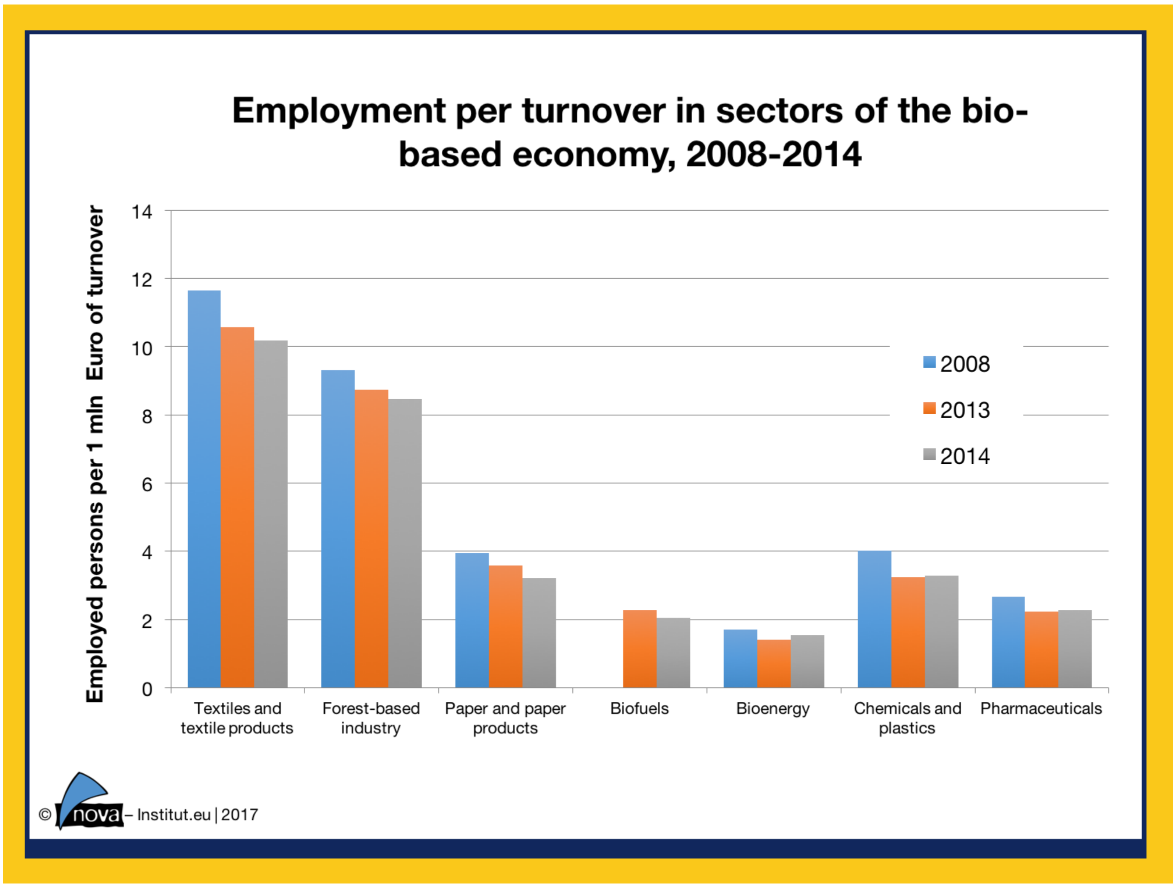


Figure 31: Employment per turnover in sectors of the bio-based economy, 2008-2014
Source: nova-Institute 2017, own research

4.1.3.6 Bio-based shares in the manufacture of chemicals and chemical products (Comparison between 2008, 2013 and 2014)

The following figure compares the estimated overall bio-based share in the NACE Division 20 (Chemicals and chemical products) between 2008 and 2013 for the EU-28 as well as for the single Member States. Since it is very difficult to estimate changes in bio-based shares per product between these two years, for each product the same share has been assumed for all three years. Therefore, the differences result mostly from changing total production volumes.

The data show an overall increase in the bio-based share in the EU-28 from 5.7% in 2008 to 7.0% in 2014. The raw material for the chemical industry is about 50% organic (fossil and bio-based) and about 50% inorganic (minerals, metals).

Only taking the organic part into account, the overall bio-based share increased from 11% in 2008 to 14 % in 2014.

Denmark stands out as the one Member State with the highest bio-based share in the chemical industry in 2013, which is mainly due to the high production of enzymes. Latvia and Sweden are following primarily due to a large production volume of charcoal and tall oil.

The results, calculated for the first time with this methodology, are in line with different estimations on Member State level.

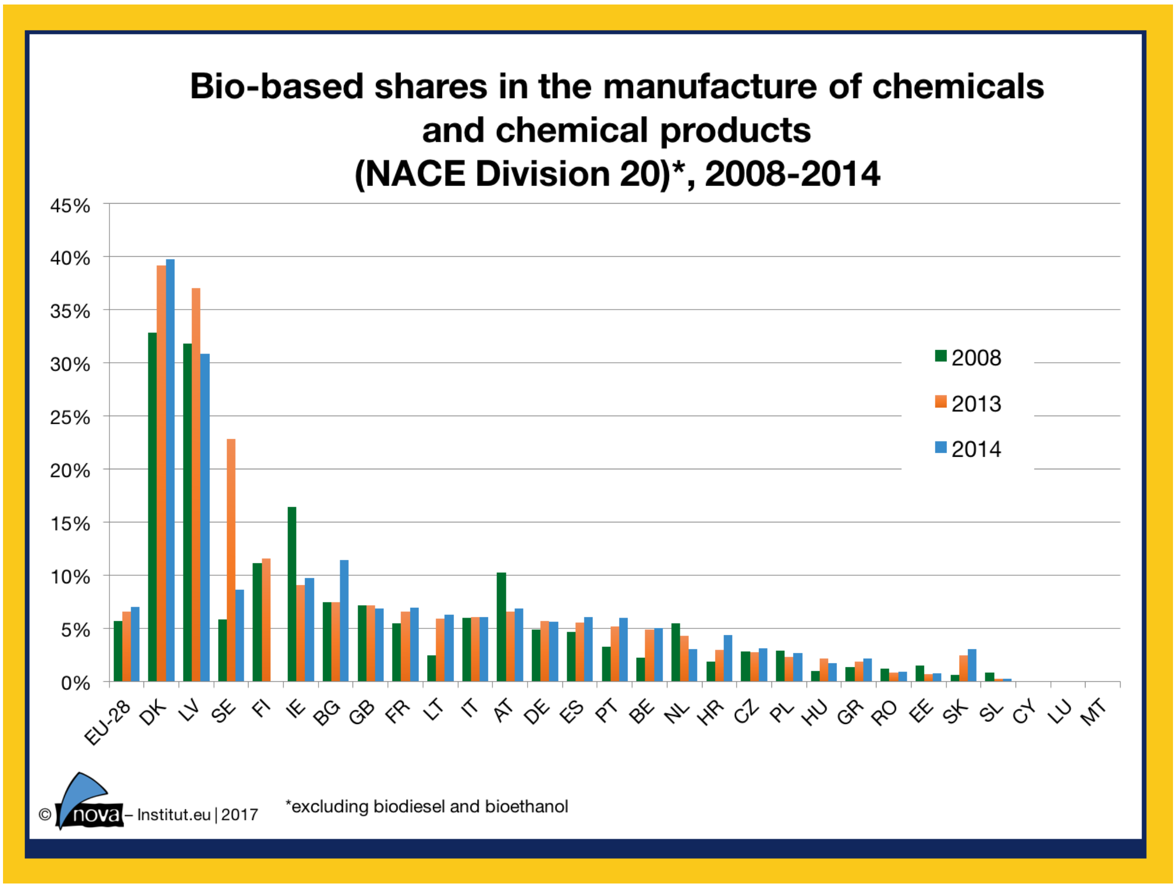


Figure 32: Bio-based shares in the manufacture of chemicals and chemical products, 2008-2014.
Source: nova-Institute 2017, own research

The final Figure 33 shows in more detail which NACE Classes have contributed to the overall increase of the bio-based share of the chemical industry. The picture illustrates the share of the different (partly and fully) bio-based classes to the turnover of the *whole* chemical sector (Division 20). For example, the 2% share of bio-based "Other organic basic chemicals" means that bio-based "Other organic basic chemicals" account for 2% of the overall turnover of Division 20, "Chemicals and chemical products". This means that if one adds all the bars, they amount to roughly 7% – which is the complete share of bio-based chemicals in the total production of chemicals. The table below the graph provides further clarification. Apparently, the highest overall contribution as well as the highest increase in the period from 2008 to 2014 is due to essential oils (NACE Class 20.52). Also, plastics (Class 20.16) have increased their contribution significantly. Other organic basic chemicals steadily continue to make a high contribution with about 2% of the total bio-based share in this Division.

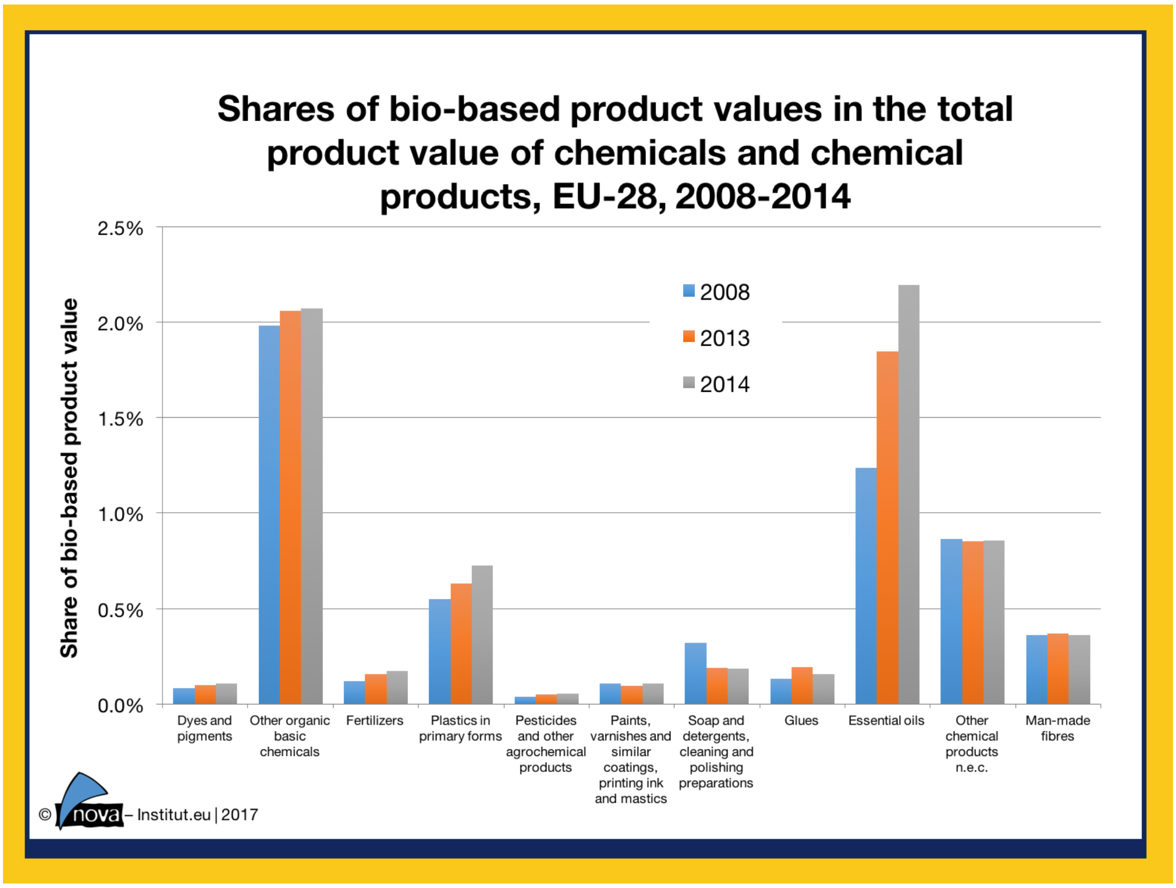


Figure 33: Shares of bio-based product values in the total product value of chemicals and chemicals products, 2008-2014.
Source: nova-Institute 2017, own research

The following table illustrates further how the increase in production value of certain fully bio-based chemicals contributes strongly to a growth of bio-based chemicals as a whole:

Table 20: Increase in production values of fully bio-based products in PRODCOM

Product	**Bio-based share**	**Share in production value of D20 in 2013**	**Share in production value of D20 in 2014**	**Increase in share in production value of D20 in 2014-2013**
Tanning extracts of vegetable origin	100%	0.01%	0.02%	+30%
Yarn of viscose rayon filament	100%	0.01%	0.02%	+98%
Natural and modified natural poly-	100%	0.23%	0.31%	+35%
Odoriferous substances	100%	1.08%	1.43%	+32%

Source: Eurostat, calculations nova-Institute

4.2 Public and private investment

Table 21: Studies and reports on investment in bioeconomy

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	World-wide Investments in Bio-based Chemicals	nova-Institute, 2012	Overview table of investments in bio-based production facilities. Focus on bio-based chemicals, only very few fuels included. Information includes the company investing, where it is based, where the investment is made (region and country), production capacity invested in and in a few instances also the amount of money invested. Lists approximately 70 investment projects worldwide, quoting news articles, press releases and some scientific publications.	nova publication based on older data, but the only overview publication available[56]
2	Biobased investment climate in the Netherlands and Europe. Summary results quick scan.	Suurs, R., Roelofs, E., 2014	Quick scan executed for the Dutch government aimed to assess the investment climate in bio-based industries in the Netherlands and Europe, by addressing the following specific three questions: 1. Which criteria determine the outcome of planning bio-based investment decisions? 2. What is the relative country performance within and outside Europe? 3. What are the specific barriers for investing in the Netherlands and Europe? The results are structured by investments in three different scales of plants: R&D capacities / pilot plants; demonstration plants / semi-commercial; commercial production / upscaling. As overall conclusion, the report identified the following as main EU strengths: • R&D support • Knowledge infrastructure • Logistics infrastructure (port / inland) • Emerging bio-based niche markets And the following as main EU weaknesses: • Feedstock costs and security of supply • Energy costs • Tax pressure / lacking financial incentives	Publication in Dutch, summary available in English[57]

[56] http://bio-based.eu/download/?did=1607&file=0
[57] http://bio-based.eu/download/?did=1726&file=0

			• Lack of "valley of death" capital In the comparison with other regions, the study identified several weaknesses of the EU, especially in terms of tax incentives and financial support compared to the Americas and Asia.	
3	Study on investment climate in bio-based industries in the Netherlands	Dammer, L., Carus, M., 2014	This study presents the results of a short study that investigated the barriers faced by small companies active in bio-based economy when they want to acquire investment for their businesses. The study was conducted from January to May 2014 in the form of 13 interviews with start-ups or other SMEs in the Netherlands, Germany, France and Belgium and was complemented by selected literature. The focus was exclusively on bio-based chemicals and materials, not on food, feed or energy produced from biomass. The objective of this study was to assess the investment climate for bio-based industries in the Netherlands in comparison to other countries. The main research questions were: 1. Which reasons move investors to provide money for bio-based entrepreneurs? 2. What are the advantages of the Netherlands as a location for bio-based industries? 3. Which hurdles might prevent investors from placing their funds in the Netherlands and which conditions make other locations potentially more attractive for investing? The strongest point of criticism identified in the study was the structure of public funding programmes. Existing public funding schemes were positively mentioned by many interview partners mainly for research and development, but many lamented a lack of public support for the following stages, namely pilot and demonstration as well as commercialization. Existing mechanisms were also criticized for complexity and slowness as well as the dominating requirement of including big universities or companies in consortia in order to obtain grants. Concerning the acquisition of funds other than public support, three options became apparent: Bank loans, investment from risk capital or investment from strategic partners, i.e. other companies interested in a cooperation or in using the bio-based materials for their own products. Several participants stated that the bank system fails innovative entrepreneurs completely. Even with government guaranteeing for 50% of the risk as is done by some public programmes, most banks still shy away from the investment. This	nova study[58]

[5858] http://bio-based.eu/download/?did=1719&file=0

			is a massive problem for European entrepreneurs. Other aspects, such as lack of tax incentives for innovation, missing standard of bio-based products, labelling, GMO regulations and infrastructure are also listed and discussed in the report.	
4	Dynamics of Venture Capital Funding in the Bio-based Chemicals Industry	Lux Research, 2014	Article quotes the Lux Market Report by stating that the BioBased Materials and Chemicals (BBMC) sector has clearly recovered from the 2008 setback, when many start-ups performed less than expected and many went bankrupt. Investment was on the rise from 2013 onwards, and was expected to come close to $ 1 billion (€ 780 million) in 2014, a 28% increase from 2013. The analysis covers small-to-medium sized companies that devote their resources primarily or entirely to the development and commercialization of bio-based materials and chemicals. It does not include larger companies that while having some BBMC-related activities/production, have their core business focus in other fields (e.g. Braskem or DSM). With those restrictions in mind, Lux's findings still are quite remarkable. The first is the absolute dominance of North America in this field. Over the past three years, North American companies acquired a staggering 87% of the total venture capital funding of the BBMC sector over the past three years.	commercial report, summary news article available at biobasedpress.eu[59]
5	Bioeconomy Investment Summit. Unlocking EU Leadership in 21st Century Bioeconomy	Watson, R., 2015 (European Commission DG RTD)	Report gives a comprehensive record of the presentations and discussion of the Bioeconomy Investment Summit from November 2015, including the sessions • Investing in the Bioeconomy • Agriculture, food and bio-based products • From forestry to new bio-based products • Looking ahead: the marine and the bioeconomy • From bio-waste to bio-based goods and services • Facilitating investment in the bioeconomy Report contains only few concrete conclusions, since most of the contributions are more general statements on economic and political framework or examples from specific companies. There is no hard data on investment figures in the EU included.	Final report of the conference held in Brussels 9-10 November 2015[60]
6	Global sustainability megaforces in shaping the future of the European	Pätäri, S. et al. 2015	The study investigated the significance of certain megaforces (climate change, material resource scarcity and ecosystem decline, among others), and their relation to the drivers	in: Forest Policy and Economics, October 2015

[59] http://www.biobasedpress.eu/2014/10/investment-biobased-materials-chemicals-rise-says-lux-research/
[60] https://ec.europa.eu/research/bioeconomy/pdf/report_bioecosummit.draft.18Feb_noTC.pdf

	pulp and paper industry towards a bioeconomy		of sustainability-related investments in the European pulp and paper sector. It also identified threats and opportunities that these business environmental changes may bring about. The panelists interviewed in the study identified a greater demand for energy, volatility in the fossil fuel markets and increasing material resource scarcity as the most significant sustainability megaforces shaping European PPI over the next 15 years. However, all the megaforces – except for global ecosystem decline and water scarcity – were perceived as opportunities rather than threats to European PPI businesses, indicating that dedicated energy and environmental policies have the potential to advance a paradigm change towards a bioeconomy rather than curbing the future of the European PPI.	
7	Show Me the Money: Where Is Venture Capital Placing Bets in Bio-based?	Lux Research, 2016	From 2010 to 2015, the global bio-based materials and chemicals (BBMC) industry attracted nearly $ 9.2 billion in funding from corporates, debts, individuals, private equity, public investment, and venture capital (VC). Notably, VCs have been the major financing driver for start-ups and invested $5.3 billion (57%) of the total investment from 2010 to 2015.	Commercial report, only very short summary publicly available[61]

[61] https://members.luxresearchinc.com/research/report/21604

4.2.1 Key findings of the assessed studies

There is not a lot of bioeconomy-specific investment information freely available. Lux Research publishes commercial reports (last editions from 2014 and 2016), but the publicly accessible data is very limited.

A publication by nova-Institute from 2012 made an attempt of providing an overview of investments in bio-based chemicals, based on information collected from press releases, news articles and some scientific publications. The list includes about 70 investment projects. A break-down of the numbers shows that the investments are more or less evenly distributed across the globe, at least by production capacities:

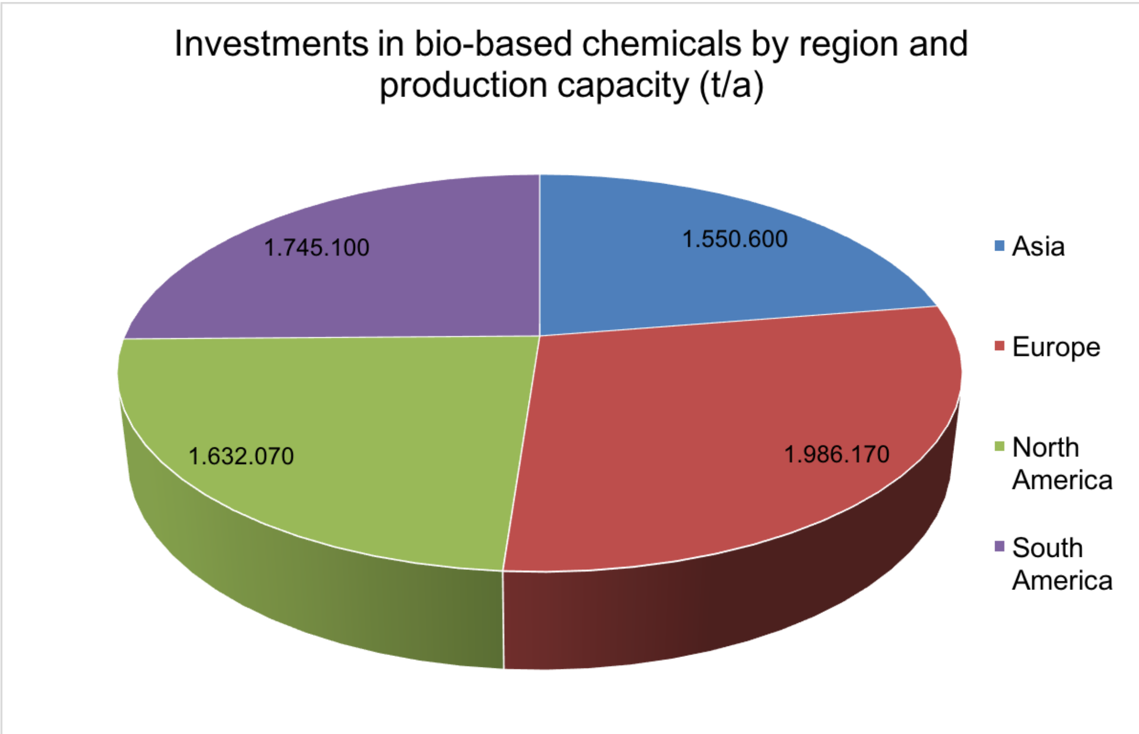


Figure 34: Investments in bio-based chemicals by region and production capacity
Source: own calculations, based on nova-Institute 2012

When it comes to number of investment projects, however, Europe and North America show higher numbers than Asia and South America:

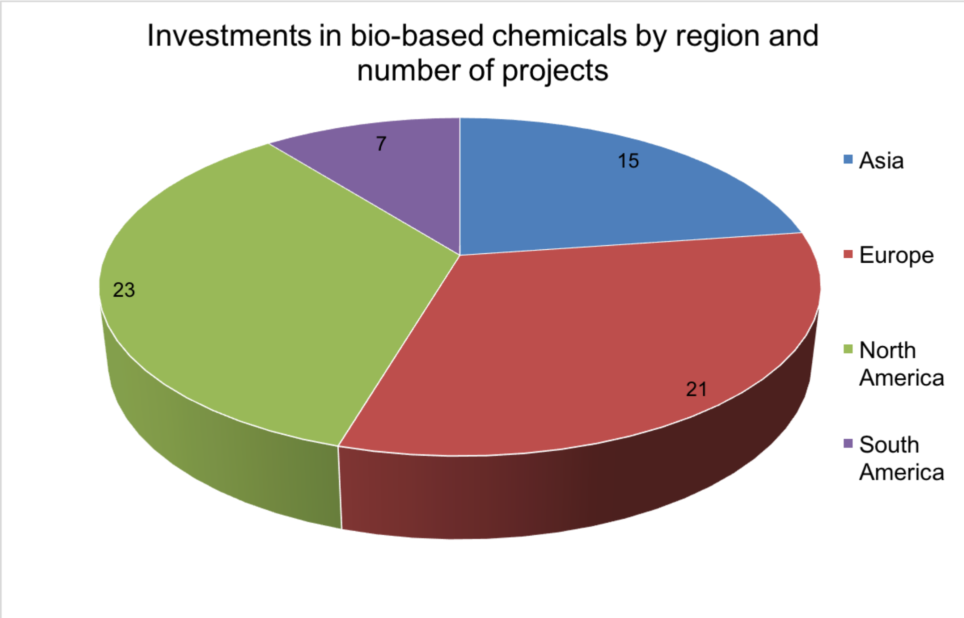


Figure 35: Investments in bio-based chemicals by region and number of projects

Source: own calculations, based on nova-Institute 2012

The main conclusion of this comparison could be that investments in Asia and South America target predominantly larger-scale facilities, since the same production capacities are reached with a smaller number of installations. This seems to confirm the often bemoaned fact that while Europe is leading in R&D and even pilot scale facilities, commercial production facilities, based on Europe's pioneering work in the bioeconomy, are built elsewhere (see also Watson 2015). The projected development of some bio-based polymers' production is in line with this assessment:

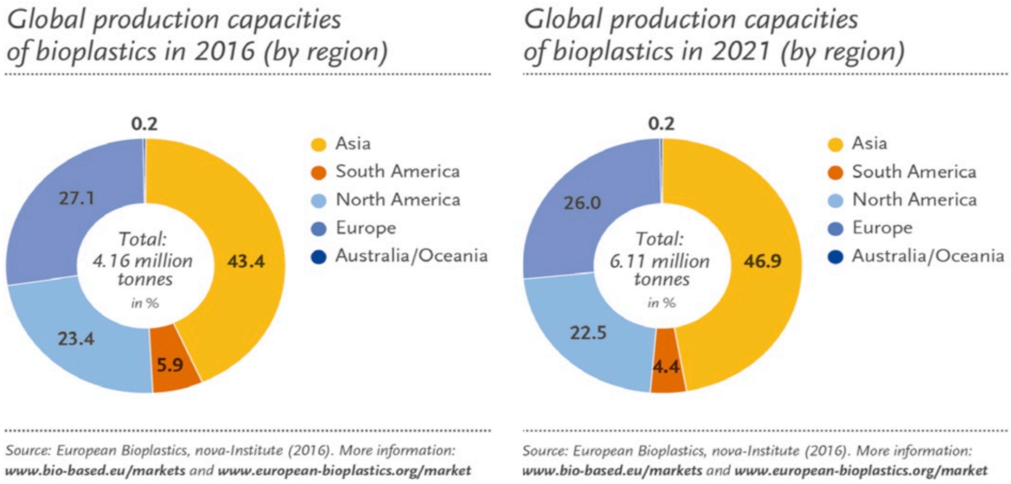


Figure 36: Evolution of bioplastics production capacities by region
Source: European Bioplastics 2016[62]

The Dutch Ministry of Economics issued two sister studies in 2014 that aimed at analysing the reasons for this investment behaviour. While one of them (Suurs & Roeloefs 2014) followed more of a top-down approach, using desktop analysis only partially supported by interviews, the other (Dammer & Carus 2014) was based exclusively on interviews with small and start-up companies active in the bio-based economy. Both studies focus on the investment climate in the Netherlands, but also draw parallels to the whole of Europe and make comparisons on a global scale.

Both studies differentiate between investment on three levels: R&D / pilot scale; demonstration plants / semi-commercial scale and commercial scale. The main investment drivers are different for these three levels, as shown in Figure 37 below. While issues such as regulation and knowledge infrastructure are decisive for investments on the R&D level, decisions on commercial scale investments are much more driven by factors such as feedstock supply, labour costs and market access.

[62] http://www.european-bioplastics.org/news/publications/

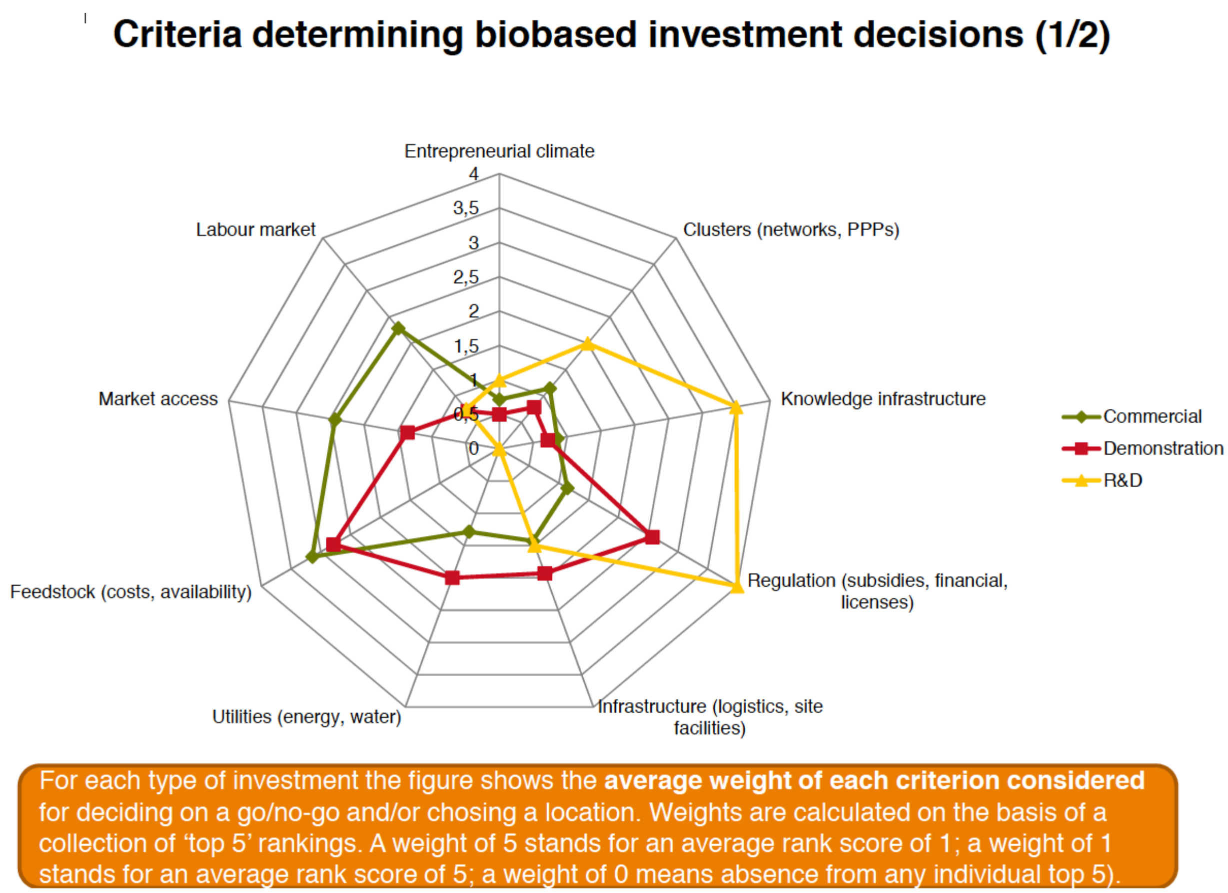


Figure 37: Criteria determining biobased investment decisions
Source: Suurs & Roelofs 2014

The studies came to the conclusion that other parts of the world are much better equipped to provide companies with what they need and to meet the criteria summarised in Figure 37:

Table 22: Fulfilment of decision making criteria for bio-based investments – global comparison

Within Europe differences are relatively small

	Europe				N-America	S-America	Asia	
	NL	BE	DE	FR	VS	Brazilië	Thailand	China
Feedstock: costs and availability	-	-	-	-	++	++	++	?
Utilities: energy costs	-	-	-	-	++	+	+	++
Infrastructure: logistics	++	++	+	+	+	+	+	+
Knowledge infrastructure	++	++	++	++	++	?	?	?
Regulation: R&D support	++	++	++	++	++	?	?	?
Regulation: incentives / taxes	-	-	-	-	+	?	++	++
Entrepreneurial culture	+	?	-	+	++	?	?	?
Market access / demand	*	*	*	*	*	*	*	*

Country comparison of key decision making criteria for allocating of biobased investments.
? Unknown / Ambiguous
* Company or product specific

Source: Suurs & Roelofs 2014

The latest available numbers on the investment by venture capital firms are available through the very short public summary of the 2016 Lux Research report:

> From 2010 to 2015, the bio-based materials and chemicals (BBMC) industry attracted nearly $9.2 billion in funding from corporates, debts, individuals, private equity, public investment, and venture capital (VC). Notably, VCs have been the major financing driver for start-ups and invested $5.3 billion (57%) of the total investment from 2010 to 2015.

In 2014, the staggering majority of such VC funding went to American companies:

Share	Country
0.02%	Argentina
0.56%	Australia
0.48%	Belgium
5.27%	Canada
0.20%	Finland
0.81%	France
0.50%	Germany
2.58%	Israel
2.46%	Netherlands
0.76%	Norway
0.12%	Spain
0.36%	Sweden
1.69%	Switzerland
2.02%	United Kingdom
82.19%	United States

Figure 38: Share of VC funding in bio-based materials and chemicals by countries

Source: Lux Research 2014, quoted in biobasedpress.eu

However, all of these numbers need to be interpreted carefully, since the focus of analysis is not always the same (sometimes all bio-based products, sometimes only chemicals, sometimes unclear).

4.2.2 Discussion and identification of gaps

As mentioned in the beginning of the analysis, there is very little information freely available when it comes to investment in the bioeconomy. Apart from the often-quoted 3.7 billion € investment to be made by BBI from 2014-2020, of which 2.7 billion € have been pledged by the industry and 1 billion are public investment, the only other figures on absolute amounts of investment were to be found in the commercial report by Lux Research, quoting $9.2 billion of funding attracted globally by bio-based chemicals and materials from 2010-2015. On top of the pledges made within the BBI, BIC's annual survey showed that its members had around €2 bn investments in Europe in the pipeline in 2015. This increased to €4 bn in 2016, and around €4.5 in 2017. It is unclear to which time horizon "in the pipeline" refers (personal communication).

It is therefore not surprising that the political discussions, which are excellently summarised by the report on the Bioeconomy Investment Summit (Watson 2015), are marked by pretty general statements, overarching calls for action or – at best – specific company case studies.

One interesting attempt has been made to collect more information on investments in bio-based businesses and make them publicly available, namely by the Recreate project. They have put up a database[63] depicting "early stage investments in bioeconomy", with a focus both on chemicals and on energy. However, the results are difficult to interpret (and have therefore been left out of the analysis) and the data behind them is "patchy" at best, as discussed[64] by the project members themselves.

The studies by Suurs & Roelofs as well as by Dammer & Carus (both 2014) provide some solid insights into motivations behind investment decisions. They could function as a basis for further research into the topic, but already provide good policy recommendations. Tax pressure and feedstock supply (access to feedstock because of competition to the bioenergy/biofuel sector)) are major hurdles for investments in Europe – these could be addressed by policy. But effective policies addressing these issues are still lacking.

[63] http://green-horizons.eu/indicator/early-stage-investment-bioeconomy-gdp-ppp
[64] http://green-horizons.eu/content/presidency-trio-and-bioeconomy

5 Climate change mitigation and environmental aspects

5.1 GHG emission reduction and climate change mitigation

Table 23: Studies relevant to GHG emission reduction and climate change mitigation

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	Life Cycle Assessment of end-of-life options for two biodegradable packaging materials: In support of flexible application of the European Waste Hierarchy	Rossi, V., et al. 2012	Life cycle assessment (LCA) was applied to two biodegradable plastics: Polylactic acid (PLA) and Thermoplastic starch (TPS). Several end-of-life options were studied: mechanical recycling, industrial composting, anaerobic digestion, direct fuel substitution in industrial facility, incineration with heat recovery and landfill. For most indicators, mechanical recycling appears as the preferred end-of-life option, in line with the EU Waste Hierarchy. The direct fuel substitution in an industrial facility also appears as an interesting option, competing with recycling from an environmental perspective. Composting has higher impacts than municipal incineration, while the Waste Hierarchy suggests a preference for composting compared to municipal incineration. Anaerobic digestion lies between municipal incineration and direct fuel substitution, within the group of end-of-life options that recover energy. Finally, landfill does not provide important benefits, but has very low impacts for most indicators, even lower than composting, in clear contradiction with the Waste Hierarchy, except in the case of TPS for global warming: the degradation of this material in landfill could cause large amounts of methane emissions, dominating all other end-of-life options. LCA shows that the EU Waste Hierarchy is not always valid for biodegradable plastics, especially looking at the benefits that can be expected from composting. The EU Waste Hierarchy should be taken with care for these materials: its concept is a good general rule, but a full LCA is advised before taking a final decision.	Link here[65]

[65] http://avnir.org/documentation/book/LCAconf_rossi_2012_en.pdf

2	Baseline time accounting: Considering global land use dynamics when estimating the climate impact of indirect land use change caused by biofuels	Kløverpris, J. H., & Mueller, S., 2012	The purpose of this paper is to propose a new method (baseline time accounting) that takes global land use dynamics into account that is consistent with the global warming potential, that is applicable to any phenomenon causing land use change, and that is independent of production period assumptions. The global dynamic development in land use has important implications for the time accounting step when estimating the climate impact of ILUC caused by biofuel production or other issues affecting land use. Ignoring this may lead to erroneous conclusions about the actual climate impact of ILUC. Several land use projections indicate that the global agricultural area will keep expanding up to and beyond 2050.	
3	Harmonisation and extension of the bioenergy inventories and assessment	Emmenegger, M., et., 2012	Although biofuels can allow the reduction of fossil fuel use and of greenhouse gas emissions, they often shift environmental burdens towards land use-related impacts. Indeed, only very few biofuel pathways show lower or at least no higher impacts for all indicators than the fossil fuels. The most promising pathways are those based on methanisation of residues or on reforestation activities.	Link here[66]
4	Sustainability of bio-based plastics: general comparative analysis and recommendations for improvement	Álvarez-Chávez, C.; et al., 2012	Bio-based plastics appear to be more environmentally friendly materials than their petroleum-based counterparts when their origin and biodegradability are compared. But which of the bio-based plastics currently on the market or soon to be on the market are preferable from an environmental, health, and safety perspective? This analysis found that none of bio-based plastics currently in commercial use or under development are fully sustainable. Each of the bio-based plastics reviewed utilizes: genetically modified organisms for feedstock manufacture and/or toxic chemicals in the production process or generates these as by-products, and/or co-polymers from non-renewable resources. When deciding to substitute conventional petroleum-based plastics with bio-based plastics, it is important to understand the flow of these materials and their adverse impacts in all parts of their life cycles in order to select a material that is more sustainable.	Link here[67]
5	A Review of the Environmental Impacts of Biobased Materials	Weiss, M.; et al., 2012	Concerns over climate change and the security of industrial feedstock supplies have been opening a growing market for biobased materials. This development, however, also presents a challenge to scientists, policy makers, and industry because the production of biobased materials requires land and is typically associated with adverse environmental effects. The reviewed literature suggests that one metric ton (t) of biobased materials saves, relative to conventional materials, 55 ± 34 gigajoules of primary energy and 3 ±	Link here[68]

[66] https://www.researchgate.net/profile/Rainer_Zah/publication/233739532_Harmonisation_and_extension_of_the_bioenergy_inventories_and_assessment/links/02e7e51a457be59e34000000/Harmonisation-and-extension-of-the-bioenergy-inventories-and-assessment.pd
[67] http://www.advancesincleanerproduction.net/third/files/sessoes/5B/7/Alvarez-Chavez_CR - Paper - 5B7.pdf
[68] https://epub.wupperinst.org/files/4276/4276_Weiss.pdf

			1 t carbon dioxide equivalents of greenhouse gases. However, biobased materials may increase eutrophication by 5 ± 7 kilograms (kg) phosphate equivalents/t and stratospheric ozone depletion by 1.9 ± 1.8 kg nitrous oxide equivalents/t. common to most biobased materials are impacts caused by the application of fertilizers and pesticides during industrial biomass cultivation. Clearly these impacts should be considered when evaluating the environmental performance of bio-based materials.	
6	Bio-economy and sustainability: a potential contribution to the Bio-economy Observatory	Nita, V., et al., 2013	In response to the need for further clarifications concerning the emerging concept of the "bio-economy", the present study scrutinizes this concept in order to better delineate its analytical scope. It also describes methodologies of potential relevance to evaluation and monitoring of the bio-economy. Although not directly intended to prepare the ground for the future EU Bio-economy Observatory (BISO), the material presented therein may also meaningfully inform the design of monitoring activities which will be undertaken within the BISO framework.	JRC report Link here[69]
7	The future of Agriculture: Scenarios for sustainable farming in Denmark	Aarhus University and Kobenhavns Universitet, 2014	This study used scenario analysis in which four different imaginary scenarios of possible futures are presented on equal footing. The scenarios each focus on different kinds of sustainability. They are thought up to be somewhat complementary with regards to the degree of integration of environmental considerations in production and priorities between agricultural production and other considerations for scenery, environment and society. The four selected scenarios are: Green Growth, Urban and Rural, The Biobased Society and A Rich Nature. The loss of nitrogen and phosphor to the aquatic environment will be reduced remarkably because of set-aside of cultivated land, cover crops, buffer zones and conversion to organic farming. In the 'Green Growth' scenario mainly aims to minimize the pollution and climate impact due to farming while maintaining and improving potentials for growth in agriculture. The sub-objectives are: • Effective handling of nutrients from agriculture • Reduced emission of greenhouse gases. Most of them live in closed barns year round to fully control the emission of ammonia and greenhouse gases. • Reduced use of pesticides.	Link here[70]
8	A bioeconomy to fight climate change	van Renssen, S., 2014	The use of biomass for energy generation is helping European Union countries meet their renewable energy and emissions targets, but demand from other sectors means policy needs to be developed for maximum climate benefits. In its 2030 climate and energy proposals, the European Commission acknowledged the need for 'an improved biomass policy' to maximize its resource-efficient use, deliver real greenhouse-gas emissions savings, and allow for 'fair competition' between energy and non-energy uses.	

[69] https://biobs.jrc.ec.europa.eu/sites/default/files/generated/files/documents/2013 JRC Report Bioeconomy and Sustainability.pdf
[70] http://fremtidenslandbrug.dk/wp-content/uploads/2015/02/Main-report-English-summary-future-farming.pdf

9	Natural capital and bioeconomy: challenges and opportunities for forestry	Marchetti, M., et al., 2014	Overview of the bioeconomy-based natural resources management (with a focus on forest ecosystems), by analyzing the related challenges and opportunities, from international to national perspective, as in Italy. To create the suitable conditions for bioeconomy and green growth, the following insights have to be denoted: (i) a deeper understanding of natural capital and related changes; (ii) the improvement of public participation in decision-making processes.	Link here[71]
10	An innovative perspective: Transition towards a bio-based economy	van Beeck, N.; Moerkerken, A., Kwant, K., & Stuij, B., 2014	Cascading is a precondition in the transition towards a bio-based economy, as part of the concept of the 'Trias Biologica', which is a logical concept to feed both people and livestock, to produce enough materials and energy to meet demand, *and* at the same time stay well within the planetary boundaries. Trias Biologica. First of all, a *de-carbonization* of the economy is necessary. Secondly, fossil carbon need to be substituted with sustainably produced bio-based carbon. And thirdly, cascading of the biomass is required. De-carbonizing is mainly targeted at the energy system. This *substitution* is the second component of the Trias Biologica. It is essential that this bio-based carbon is produced and consumed in a sustainable manner, in order to stay well within the planetary boundaries. *Cascading* is an essential element in sustainable agriculture, in order to optimize the use of bio-based resources with bio-refinery and circular process chains. This approach involves bio-refinery to extract minerals and other useful products in waste streams, making optimum use of every next step in the refinery process. Cascading also implies production chains being made more circular, by reusing minerals at the place of extraction as much as possible to avoid local depletion or eutrophication of the soil.	
11	Sustainable biomass for energy and materials: A greenhouse gas emission perspective	van Hilst, F.; et al. 2015	Bioenergy is a major source of renewable energy. However, its sustainability is debated in both the scientific arena and the public domain. Food vs energy debate, is not about whether or not to use biomass but about how to produce biomass so that it indeed reduces emissions compared to fossil fuels. Wang and Dunn (2015) point out that by-products of biofuel production are not included in the analysis although they supply food or feed that does not need to be produced elsewhere. A sound design of bioenergy policies is the key (particularly in combination with carbon capture and storage) in limiting climate change	Link here[72]
12	Environmental Sustainability Assessment of Bioeconomy Products and Processes	De Matos, C. T., et al., 2015	Provides environmental factsheets from cradle to grave of several value chains / products belonging to the the bioeconomy, as part of the Bioeconomy Observatory, e.g. for chicken eggs, cow's milk, but also for 1,3-propanediol, glycerol, lactic acid, polylactid acid, polyhydroxyalkanoates and others.	Link here[73]

[71] cra-journals.cineca.it/index.php/asr/article/download/1013/pdf_32
[72] https://www.uu.nl/sites/default/files/sustainable_biomass_for_energy_and_materials.pdf
[73] http://publications.jrc.ec.europa.eu/repository/bitstream/JRC96713/lb-na-27356-en-n.pdf

13	Carbon Footprint and Sustainability of Different Natural Fibres for Biocomposites and Insulation Material	Barth, M., and Carus, M., 2015	Natural fibres are an environmentally friendly alternative to glass and mineral fibres. In the last twenty years, more and more natural fibres have started being used in biocomposites, mainly for the automotive sector and also as insulation material. Natural fibres such as flax, hemp, jute or kenaf are being used more and more in technical applications. The carbon footprint of these natural fibres is much lower than their counterparts glass and mineral fibres. However, the initial advantage natural fibres have over glass fibres decreases for the final product, because further processing steps offset their carbon footprint. Nevertheless, natural fibre composites have a 20–50% lower carbon footprint compared to glass fibre composites.	Link here[74]
14	Life Cycle Impacts of Natural Fiber Composites for Automotive Applications	Boland, C. S., et al. 2015	This study examines the life cycle energy demand and greenhouse gas (GHG) emissions associated with substituting natural cellulose and kenaf in place of glass fibers in automotive components. For all vehicles, compared to the baseline glass fiber component, using the cellulose composite material reduced life cycle energy demand by 9.2% with powertrain resizing (7.2% without) and reduced life cycle GHG emissions by 18.6% with powertrain resizing (16.3% without), whereas the kenaf composite component reduced energy demand by 6.0% with powertrain resizing (4.8% without) and GHG emissions by 10.7% with powertrain resizing (9.2% without). For both natural fiber components, the majority of the life cycle energy savings is realized in the use-phase fuel consumption as a result of the reduced weight of the component.	
15	Transformation paths to a low-carbon bioeconomy in Austria	Kalt, G. et al., 2015	A modelling approach for developing integrated transformation scenarios is presented. It is implemented in the optimization environment TIMES and comprises a complete representation of the Austrian energy system, the forest sector, agricultural land use and production, the livestock sector, food supply and demand. The model is basically intended to represent all relevant material and energy flows between these sectors. The core objective is to develop integrated scenarios and identify efficient GHG mitigation options. The net GHG effect of increased wood removals from forests for the purpose of energy production is initially negative, as carbon stocks become lower. Only after about three decades, the net GHG effect becomes positive in this scenario. Substituting carbon-intensive materials with long-lived wood products is a highly efficient way of GHG mitigation.	Link here[75]
16	A Circular Bioeconomy with Biobased Products from CO_2 Sequestration	Mohan, S. V., 2016	Although existing natural and anthropogenic CO_2 sinks have proven valuable, their ability to further assimilate CO_2 is now questioned. Thus, the paper highlights the importance of biological sequestration methods as alternate and viable routes for mitigating climate change while simultaneously synthesizing value-added products that could sustainably fuel the circular bioeconomy. The biorefinery models discussed in this context could open up new avenues to convert CO_2 to several valuable products, materials, and fuels, which could help close the carbon cycle. Despite the impressive outputs that these sequestration methods are bound to offer, certain road blocks are inevitable because of the complexity of integrating	

[74] http://bio-based.eu/?did=14089&vp_edd_act=show_download
[75] https://www.energyagency.at/fileadmin/dam/pdf/projekte/klimapolitik/4DO.1.1_-_Transformation_paths_to_a_low-carbon_bioeconomy_in_Austria_-_Kalt_et_al_2015.pdf

			various processes and the function of various microbial communities that are a part of those processes. Sequential integration of various bioprocesses with efficient biocatalysts might prove to be the most promising route for CO_2 amelioration with value addition. The concept of CO_2 biorefinery is still in an early stage. Resolving all of the issues pertaining to the implementation of efficient and sustainable CO_2 conversion technologies necessitates more structured actions, inter- and cross-disciplinary research, and coordinated governmental collaboration.	
17	The Bioeconomy, Climate Change, and Sustainable Development	Chum, H. L., 2016	Overarching presentation on bio economy strategies around the world and GHG mitigation	Link here[76]
18	Bio-based economy and climate change – Important links, pitfalls and opportunities	Carus, M., 2017	There is a strong link between bio-based economy and climate change. • In terms of adaptation, bio-based economy, if implemented sustainably, can offer opportunities to farmers, since a more diverse production of crops for food, feed and industrial markets can provide more security and stability. Through the local production of feedstocks for bioenergy and bio-based products, farmers become more resilient and can adapt better to climate change, which is especially beneficial for the socio-economic development of rural areas. • So far, biomass is the only renewable carbon source for organic chemicals and the plastic industry, which provide so many important goods for people's daily life. Using biomass in these applications is crucial in order to lower the release of GHG emissions. **While bio-based economy can significantly contribute to climate change mitigation, it is not by default a climate friendly concept.** Along bio-based products' value chain, from biomass production to the final product, there are additional GHG emissions (on top of what is released at the end of the product's lifecycle). Moreover, direct and indirect land use changes can cause significant GHG emissions linked to the production of bio-based products and the bio-based economy. Currently, some companies seek to source their feedstock for bio-based products from local agriculture, instead of importing it. This is due to the impacts of climate change on agriculture in subtropical climates, from which some types of biomass are commonly imported. An example of this can be locally sourced rubber from dandelion instead of tropical rubber trees. The shift to local / regional production aims to reduce the risks of short supply of biomass from these areas. To locally source the biomass would bring about GHG emission reductions from transportation, but it could also bring (i)LUC and related emissions. • Additionally, bio-based products temporally sequester carbon during their lifespan. This can be only a few days (for packaging) or even 50 to 100 years (in buildings).	nova study for FAO, singular in its overarching perspective and in looking at the 'big picture' rather than investigating single cases

[76] http://www.nrel.gov/docs/fy16osti/66687.pdf

			To realise the full climate mitigation potential of bio-based products, biomass production in agriculture and forestry needs to be improved by: • using sustainable agriculture intensification, e.g. precision farming and soil and water conservation; and other climate-smart agriculture practices; and • avoiding direct and indirect land use changes. The cascading use of biomass, with the substitution of several fossil-based products along the cascade stages, can lower the release of GHG emissions and increase resource efficiency and carbon sequestration. However, in order to fully realize these potentials, the energy input for collection, separation and recycling needs to be as low as possible. This is mainly a logistical challenge. Finally, the most suitable 'end of life options' for the different bio-based products and their applications have to be identified and implemented.	

5.1.1 Key findings of the assessed studies

The mere number of existing studies shows that there is a **strong link suspected between bio-based economy and climate change**. If implemented sustainably, the bio-based economy can, while having a potentially positive impact on the environment, also offer opportunities to farmers, since it can provide more security and stability. **Biomass is the only renewable carbon source for organic chemicals and the plastic industry**. However, **while bio-based economy can significantly contribute to climate change mitigation, it is not by default a climate friendly concept**. GHG emissions are created along a bio-based product's value chain, from biomass production to the final product. On top of this, there are additional GHG emissions released at the end of the product's lifecycle. (Carus 2017)

Therefore, the European Commission has acknowledged the need for 'an improved biomass policy' to deliver real greenhouse-gas emissions savings, maximize its resource-efficient use, and allow for 'fair competition' between energy and non-energy uses, including materials and food (van Renssen 2014). To add to the potential environmental benefits, the bio-based economy can also offer opportunities to farmers, since it can provide more security and stability. (Carus 2017)

5.1.1.1 Carbon sequestration and GHG emission reduction

Bio-based products temporally sequester carbon during their lifespan. This can be from only a few days (for packaging) to as long as 50 to 100 years (in buildings). This is why it is important to quantify and consider all stages of a product's lifecycle when calculating GHG net emissions. For example, the net GHG effect of increased wood removals from forests for the purpose of energy production is initially negative, as carbon stocks become lower. Only after about three decades, the net GHG effect becomes positive in this scenario (Kalt et al. 2015). Thus, substituting carbon-intensive materials with long-lived wood products is a highly efficient way of GHG mitigation (Kalt et al. 2015). Biological sequestration methods are crucial as alternate and viable routes for mitigating climate change while simultaneously synthesizing value-added products that could sustainably fuel the bioeconomy (Mohan 2016).

Though this is not a focal point in the assessed studies, some previous nova research found that so far, there is no agreed standard how to account for the carbon sequestration in the methodology of LCA. Several proposals are made, but they are still under discussion. To understand and account the full potential of sequestration by bio-based products, it is crucial to develop a standard methodology.

In the automotive industry, for example, both jute and hemp natural fibre components' majority of the life cycle energy savings is realized in the use-phase fuel consumption as a result of the reduced weight of the component (Boland et al. 2015). With regards to the overall carbon footprint of these natural fibres, it can be much lower than their counterparts glass and mineral fibres (Barth & Carus 2015).

Yet another way to bring about GHG emission reductions, namely from transportation, is the shift to local / regional production. This can also reduce the risks of short supply of biomass from these areas (Carus 2017).

Overall, the reviewed literature suggests that one metric ton (t) of biobased materials saves, relative to conventional materials, 55 ± 34 gigajoules of primary energy and 3 ± 1 t carbon dioxide equivalents of greenhouse gases (Weiss et al. 2012).

5.1.1.2 Cascading use and closing the cycle

Cascading is agreed to be a helpful aspect in the transition towards a bio-based economy (van Beeck et al. 2014). The cascading use of biomass, with the substitution of several fossil-based products along the cascade stages, can lower the release of GHG emissions and increase resource efficiency and carbon sequestration (Carus 2017). Cascading is an essential element in a more sustainable economic concept, in order to optimize the use of bio-based resources with biorefineries and circular process chains. This approach involves biorefineries to extract minerals and other useful products in waste streams, making optimum use of every next step in the refinery process. Cascading also implies production chains being made more circular, by reusing by-products at the place of extraction as much as possible to avoid local depletion or eutrophication of the soil (van Beeck et al. 2014).

The previously discussed concept could be extended to the **CO_2 Economy**. Technology like CO_2 refineries could open up new avenues to convert waste (CO_2) to several valuable products, materials, and fuels, which could help close the carbon cycle. However, certain road blocks are inevitable as the concept of CO_2 refinery is still in an early stage (Mohan 2016).

5.1.1.3 Land use change

Direct and indirect land use changes can cause significant GHG emissions linked to the production of bio-based products and the bio-based economy. Ignoring this may lead to erroneous conclusions about the actual climate impact of ILUC, particularly as several land use projections indicate that the global agricultural area will keep expanding up to and beyond 2050 (Kløverpris & Muller 2012). Although biofuel and materials production can allow the reduction of fossil fuel use and of greenhouse gas emissions, they often shift environmental burdens towards land-use related impacts. Indeed, according to Emmenegger et al. 2012, only very few biofuel pathways show lower or at least no higher impacts than the fossil fuels. The most promising pathways are those based on methanisation of residues or on reforestation activities. The former can be further optimized with the use of livestock in closed barns year round to fully control the emission of ammonia and greenhouse gases (Aarhus University 2014).

5.1.1.4 Other environmental impacts

A growing sector in the bio-based economy are bio-based plastics. Bio-based plastics may appear to be more environmentally friendly materials than their petroleum-based counterparts when their origin and biodegradability are compared (Álvarez-Chávez et al. 2012). However, none of bio-based plastics currently in commercial use or under development are fully sustainable. This is due to the fact that production process of bio-based plastics is not hazard-free. As with other sectors of the bioeconomy, when deciding to substitute conventional petroleum-based plastics with bio-based plastics, it is important to understand the flow of these materials and their adverse impacts in all parts of their life cycles in order to select a material that is more sustainable (Álvarez-Chávez et al. 2012).

The **food vs energy debate shifts from whether or not to use biomass but about how to produce biomass** so that it indeed reduces emissions compared to fossil fuels. An example of this are biofuel production by-products that are not included in the analysis although they often supply food, feed or material building blocks that do not need to be produced elsewhere (van Hilst et al. 2015).

One last common criticism to most bio-based materials are impacts caused by the application of fertilizers and pesticides during industrial biomass cultivation (Weiss et al. 2012). These can have severe adverse effects at the source and downstream. However, using principles like cascading, the loss of nitrogen and phosphor to the aquatic environment can be reduced remarkably because

of set-aside of cultivated land, cover crops, buffer zones and conversion to organic farming (Aarhus University 2014).

Finally, the most suitable 'end of life options' for the different bio-based products and their applications have to be identified and implemented in order to mitigate GHG emissions (Rossi et al. 2012). LCA shows that the EU Waste Hierarchy is not always valid, for example in the case of biodegradable plastics in some specific applications, especially looking at the benefits that can be expected from composting. The EU Waste Hierarchy should be taken with care for these materials: its concept is a good general rule, but a full LCA is advised before taking a final decision (Rossi et al. 2012). For most indicators, mechanical recycling appears as the preferred end-of-life option, in line with the EU Waste Hierarchy (Rossi et al. 2012). In some studies, landfill does not provide important benefits, but has very low impacts for most indicators, even lower than composting, in clear contradiction with the Waste Hierarchy. These results are very application specific. (Rossi et al. 2012)

5.1.2 Discussion and identification of gaps

Very few conclusions can be drawn from the analysed studies:

To realise the full climate mitigation potential of bio-based products, biomass production in agriculture and forestry needs to be improved by:

- using sustainable agriculture intensification, e.g. precision farming and soil and water conservation; and other climate-smart agriculture practices; and
- avoiding direct and indirect land use changes. (Carus 2017)

This can only be achieved with:

3. a deeper understanding of natural capital and related changes (Marchetti et al. 2014);
4. the improvement of governmental, scientific and public participation in decision-making processes (Marchetti et al. 2014) and
5. further investment in research technologies.

There are only very few studies that aim to provide a comprehensive overview of the complex connections between bioeconomy and climate change. This means that each study's conclusions are very dependent on the selected examples, assumptions, allocations and other methodological decisions, which makes it difficult to transfer their results to general claims. LCA methodology is an important cause for this problem, since it makes it necessary to decide on clear system boundaries, make assumptions and compare impacts with specific counterparts for each product.

It is therefore close to impossible to come to a unanimous conclusion about the environmental impact of bioeconomy as a whole which is made up of so many feedstocks, applications and pathways. The studies marked in green above (Weiss et al. 2012 and Carus 2017) make an attempt to provide at least an approximation of such conclusions.

When opening the view from climate impact to overall environmental impacts, there are also difficulties to compare certain environmental impact categories to each other in terms of importance: What is more important – GHG emissions or eutrophication? Replacing fossil fuels or land use changes? The current political circumstances focus strongly on climate impact as well as on energy security and independence from fossil resources, but the scientific literature – rightly so – points out that other impacts cannot be neglected in a wholesome view of bioeconomy. However, the adverse environmental impacts of oil or shale gas extraction are mostly neglected in the discussion about comparing environmental impacts of bio-based and conventional products.

Based on previous research, we also conclude that there is a need to develop the quality standards for LCA for bio-based products further. Only for bioenergy and biofuels, clearly defined standards exists on how to perform a comparable LCA due to the regulations in the Renewable Energy Directive (RED) and Fuel Quality Directive (FQD). Also, corresponding standards for bio-based chemicals and materials are hardly possibly because of not-definable reference products, there should be developed minimum requirements concerning the quality to increase the transparency, the comparability and the acceptance of LCAs.

To understand and account for the full potential of sequestration by bio-based products, it is crucial to develop a standard methodology on how to do this.

5.2 Organic residues as feedstock

Table 24: Studies on organic residues as feedstock

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	13 Solutions for a Sustainable Bio-based Economy Making Better Choices for Use of Biomass Residues, By-products and Wastes	Odegard, I.; Croezen, H., Bergsma, G. 2012	Cascading is an important option that deserves attention in the quest for deciding the approach that needs to be taken to achieve an efficient and sustainable bio-based economy. In this study the concept of cascading is explored and it is shown that cascading can contribute significantly to the bio-based economy. Several cascading concepts are analysed, including cascading in use, in time and in function. The total, and maximum, CO_2 benefit amounts to between 332-407 Mton CO_2 eq. per year, of which the higher figure should be regarded as an optimistic potential. This potential amounts to around 30% of the target emission reduction of 2,235 Mton CO_2 per year in the EU in 2030, relative to current emission levels. The four options with the highest potential CO_2 benefit, account for around 77% of the total benefit: straw to ethanol for chemistry; manure to biogas; grass refinery; additional paper recycling.	Link here[77]
2	Recovery of high added-value components from food wastes: Conventional, emerging technologies and commercialized applications	Galanakis, C.M., 2012	The goal of the article is to classify food waste sources and high-added value ingredients prior to exploring the recovery stages, conventional and emerging technologies applied from the raw material to the final or encapsulated product. According to the Food and Agriculture Organization, roughly one-third of the edible parts of food produced for human consumption gets lost or wasted globally. This amount accounts about 1.3 billion tn/year and reflects not only the food processing wastes, but also the "food losses" (Gustavsson, Cederberg, Sonesson, van Otterdijk, & Meybeck, 2011). Safety and cost aspects were discussed, too, while a survey of patented methodologies leading to real products was listed, with a final purpose of discussing the prevalent problems that restrict the commercialization of similar procedures. Among the many listed products, phenols and carotenoids from fruit byproducts were among the suggested since they could be applied as natural food or beverage preservatives since they extend the shelf-life of the product by delaying the formation of off-	Trends in Food Science & Technology 26 (2), August 2012, 68–87

[77] http://www.cedelft.eu/art/uploads/file/CE_Delft_2665_Cascading_of_Biomass_def.pdf

			flavors and rancidity (Oreopoulou & Tzia, 2007). Pectin could be utilized as gelling agent in confectionary or as fat replacement in meat products (Galanakis, Tornberg, & Gekas, 2010c) Protein hydrolyzates from fish by-products have also been proposed as seafood flavors for soups or surimi (Kristinsson & Rasco, 2000). The recovery of valuable compounds from food wastes is an important challenge for the field related scientists, though the commercial implementation is a complex approach depending on several parameters that should be considered. Recovered materials often receive a higher degree of scrutiny, which results in partial loss of product functionality. Experience has shown that a project focused on the recovery technologies without investigating and establishing definite food targeted applications of the final product, is doomed to fail. Researchers will soon deal with the prospect of applying emerging technologies and particularly nanotechniques with an ultimate goal to optimize overall efficiency of suggested methodologies. This concept will definitely reopen debate concerning the safety of products recovered from food wastes and the impact (beneficial or not) of recycling them inside food chain.	
3	Heat, Electricity, or Transportation? The Optimal Use of Residual and Waste Biomass in Europe from an Environmental Perspective	Steubing, B.; Zah, R., and Ludwig, C. 2012	The net environmental benefits of substituting fossil energy with bioenergy were calculated for all approximately 1500 combinations based on life cycle assessment (LCA) results. Key factors determining the optimal use of biomass are the conversion efficiencies of bioenergy technologies and the kind and quantity of fossil energy technologies that can be substituted. Provided that heat can be used efficiently, optimizations for different environmental indicators almost always indicate that woody biomass is best used for combined heat and power generation, if coal, oil, or fuel oil based technologies can be substituted. All biomass uses yield environmental benefits in a similar range as long as coal or oil based technologies can be substituted. Certain conversion routes that were not considered may be more efficient than the ethanol and biogas conversion routes, e.g. the production of biodiesel from specific biomass feedstocks such as animal fat and cooking oil and the direct combustion, gasification, or advanced second generation conversion of lignocellulosic biomass such as straw.	
4	Availability of cellulosic residues and wastes in the EU	Searle, S., and Malins, C. 2013	There is significant potential for sustainable energy from cellulosic biomass in the future. This study aims to estimate the sustainable availability of certain cellulosic wastes and residues in the EU. It calculates the availability of the cellulosic fraction of waste, agricultural residues, and forestry residues, while considering current uses of these materials and the environmental impact of utilization. The total amount of paper, wood, food, and garden waste produced in the EU is considerable, in the order of 900 million tonnes per year. However, a large fraction of this is not truly "waste," but low-value input materials from industrial processing and livestock care. Diversion of these materials from their current uses would have potentially negative knock-on effects on industry and the environment. If all the EU-based sustainably available cellulosic biomass was processed for transport	Link here[78]

[78] http://www.theicct.org/sites/default/files/publications/ICCT_EUcellulosic-waste-residues_20131022.pdf

			fuel, and accounting for energy losses in conversion, these renewable feedstocks could supply a little under 1 million barrels of oil equivalent per day. This biofuel could potentially displace 13% of road fuel consumption in the EU in 2020, and 16% in 2030. It is critical to understand that using any resource, even if it appears to be available in excess, can have complex downstream effects on markets, other uses, and the demand for other resources. Even with robust and effective policy support, some fraction of this resource is likely to be impossible to economically mobilize—the stronger the support framework, the more could be achieved.	
5	Waste or resource? Stimulating a bioeconomy	House of Lords, Science and Technology Select Committee, 2014	Much of the household waste produced in the UK is still put into landfill or incinerated (57%). While preventing the creation of waste in the first place is a laudable policy goal, it is inevitable that there will always be waste—or unavoidable by-products—such as orange peel, coffee grounds or waste gas from factories and power stations. It is important to note, however, that some waste has valid existing uses and should not necessarily be diverted into a high value bioeconomy; the spreading of manure to land, for example, is an important way of returning nutrients to the soil. Measures could be taken both to remove barriers and to facilitate the growth of this industry. Waste policy in the UK should not only consider environmental aspects, but also economic opportunities. Importance of long-term planning and strategy is stressed, responsibilities should not be spread between too many ministries. Knowledge on waste streams needs to be improved. Reducing the risk of investment in this emerging industry is also essential.	Link here[79]
6	Building a high value bioeconomy OPPORTUNITIES FROM WASTE	Hancock, M.; Rogerson, D., 2015	The report focuses on waste produced in the UK and its potential to the British bio-economy. Significant waste feedstock availability in the UK, including at least 100 million tonnes of carbon containing waste generated each year, and at least 14 million tonnes of bio-based residues from crops and forestry sources each year Of this, there is probably about 25 million tonnes of waste available which, with the right technology approach, could be converted into roughly 5 million tonnes of bioethanol with a potentially material impact on fuel supply with a value of around £2.4 billion Alongside the economic benefits, the advanced management of available carbon containing wastes and residues could help to reduce the use of petrochemicals, virgin materials and finite resources worldwide. This could contribute to reducing global carbon emissions and to increased sustainability and energy security.	UK Government, Ministry of Business, Enterprise and Energy Link here[80]
7	Mapping the potential	EFIB, 2015	Waste valorisation has been a key area of research for many years within the centre, and as coordinators for a COST Action on food supply chain waste valorisation, they have strong links with a	Link here[81]

79 https://www.publications.parliament.uk/pa/ld201314/ldselect/ldsctech/141/141.pdf
80 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/408940/BIS-15-146_Bioeconomy_report_-_opportunities_from_waste.pdf
81 http://costeubis.org/files/365

	of a waste-based bioeconomy. The European Forum for Industrial Biotechnology and the Bioeconomy (EFIB) 2015: Pre-conference workshop		range of bio-waste valorisation experts. General comments on under-exploited wastes and technologies focused on improved green methods to reduce waste volume, thus increasing the concentration of desired chemicals. Also highlighted was the importance of developing portable processing technologies i.e. CO_2 recovery equipment. In addition, it was discussed that it would be highly beneficial to be able to demonstrate processes where suitable mixtures of waste feedstocks can be identified while still allowing a convenient isolation of a target chemical. Policy aspects seem to play a major role in ensuring disruptive technologies can be successfully exploited. Firstly, the policy needs to be in place to use waste as a resource – a solution here was to classify everything as a by-product and then have to reach a number of criteria before classifying it as a waste, rather than the other way around. Also, normalising legislation and standardisation over Europe would greatly aid the foundation of markets, e.g. setting up bio-based tax incentives for production of bio-based materials. Another key factor highlighted as a driver for success was brand influence – large brands such as Coca Cola can champion a technology and jumpstart its expansion into vast markets. The bio-waste streams the groups currently thought were under-exploited included agricultural food chain wastes, food processing wastes and municipal solid waste (mainly kitchen) – one of the participants concluded that within all biowaste streams, we can utilise much more than we do today	
8	Residual Biomass: A Silver Bullet to Ensure a Sustainable Bioeconomy?	Pfau, S. F. 2015	This paper discusses conditions that determine whether the use of residual biomass is indeed sustainable. Residual biomass is only seldom purely waste and regularly fulfils other functions, such as maintaining soil quality or providing habitats. The benefits of extracting residual biomass for new applications, thus causing a resource use change (RUC), have to outweigh the loss of their former function. Not all residual biomass uses contribute to sustainability equally. Applications should be optimized to achieve various sustainability goals. Advances can be achieved through adapting technologies and logistics and increasing synergies between biomass processing sectors.	In: The Third European Conference on Sustainability, Energy & the Environment 2015 Link here[82]
9	DataM – Biomass estimates (v3): a new database to quantify biomass availability in the European Union	Ronzon, T., Piotrowski, S., Carus, M., 2015	Study assesses available methodologies to calculate the availability of agricultural residues and finds a number of limitations. Most of the current scientific work is based on coefficients, which can for example differ strongly from region to region and often lack regular emipirical confirmation.	JRC technical report[83]

[82] http://papers.iafor.org/papers/ecsee2015/ECSEE2015_17857.pdf
[83] https://biobs.jrc.ec.europa.eu/sites/default/files/generated/files/documents/2015 JRCdatam-be_tkreport.pdf

10	A Strategic European Research and Innovation Agenda for Smart CO_2 Transformation in Europe (SERIA)	Wilson, G., et al. 2016 (SCOT consortium)	(see also biofuels section) The document provides an agenda for the integration of CO_2 transformation technologies (Carbon dioxide utilization) to the European research and innovation agenda. As one of the final papers of the SCOT project (Smart CO_2 Transformation), that focused on accelerating the market development of carbon dioxide utilization, the use of CO_2 was set in the focus and bio-based products were only addressed as a side topic. Biological routes of transformation via for example microalgae are not elaborated upon. The report only mentioned the off-gases of biogenic processes as one of several potential raw materials available for CDU and emphasizes the synergies of joint activities of the bioeconomy with the CO_2-based economy within a Circular Economy strategy.	Link here[84]
11	**Joint Action Plan for Smart CO_2 Transformation in Europe (JAP)**	Armstrong, K., et al. 2016 (SCOT consortium)	(see also biofuels section) The second final SCOT document offers a joint action plan based on the R&I Agenda and gives several ideas how to overcome hurdles in the market. Like Wilson, G., et al. 2016 it mentions the off-gases of biogenic processes as one of several potential raw materials available for CDU and emphasizes the synergies of joint activities of the bioeconomy with the CO_2-based economy within a Circular Economy strategy.	Link here[85]
12	Waste biorefinery models towards sustainable circular bioeconomy: Critical review and future perspectives	Mohan, S.V., et al. 2016	This review illustrates different bioprocesses based technological models that will pave sustainable avenues for the development of biobased society. The proposed models hypothesize closed loop approach wherein waste is valorised through a cascade of various biotechnological processes addressing circular economy. The Biorefinery offers a sustainable green option to utilize waste and to produce a gamut of marketable bioproducts and bioenergy on par to petro-chemical refinery. The review explores recent advances in environmental biotechnology with respect to the possibility of using waste as renewable feedstock in the framework of biorefinery. Exploitation of waste organic residues would enhance biorefinery competitiveness and social acceptance. Anaerobic fermentation is the widely investigated strategy for H_2 production and other value added products that has successfully integrated with photosynthetic processes towards diverse high value bio-based products. Overall, different stochastic models proposed worked out in tandem focuses a holistic biorefinery approach that carries tremendous industrial potential. Hence, the entire process should be evaluated as an integrated strategy and a proper cost benefit analysis of the approach is required.	In: Bioresource Technology[86] 215, September 2016, 2-12

[84] http://www.greenwin.be/fr/documents/file/262
[85] http://www.greenwin.be/fr/documents/file/261
[86] http://www.sciencedirect.com/science/journal/09608524

13	Nordic bioeconomy 25 cases for sustainable change	Nordic Council of Ministers 2017	Proposal to the Nordic Council of Ministers on a joint Nordic bioeconomy strategy designed to stimulate innovation and support a sustainable transition in the Nordic bioeconomy. 4 main frameworks: Replace; Upgrade; Circulate; Collaborate. The "Upgrade" chapter contains nine case studies on minimizing waste or using waste for value-added products. Large focus of utilization of by-products from fisheries due to the Nordic context; but also innovative enzymatic treatment of household waste to facilitate waste separation and improving recycling.	Link here[87]

[87] https://norden.diva-portal.org/smash/get/diva2:1065456/FULLTEXT01.pdf

5.2.1 Key findings of the assessed studies

5.2.1.1 Available waste and residues and how to make use of them

While preventing the creation of waste in the first place is a laudable policy goal, it is inevitable that there will always be waste—or unavoidable by-products especially from food/feed processing —such as orange peel, coffee grounds, side-streams from milk and cheese processing or waste gas from factories and power stations (HoL, Science and Technology Select Committee, 2014). Agricultural food chain wastes (such as presented in a practical online tool by Agriforvalor.eu[88]), food processing wastes and municipal solid waste (mainly kitchen) are among some of the bio-waste streams we can utilise much more than we do today (EFIB 2015). This also is true for wastewater streams. Technologies such as innovative enzymatic treatment of household waste can facilitate waste separation and improving recycling (Nordic Council of Ministers 2017); wastewater can also be utilized with algae or bacteria. Additional waste streams like off-gases from biogenic industrial processes contain carbon as carbon dioxide, carbon monoxide and in a syngas mixture. These can be used in a C1 utilization approach via chemical or biological transformation using renewable energy to produce fuels, chemicals, polymers and minerals (Wilson et al. 2016; Armstrong et al. 2016).

According to the Food and Agriculture Organization, roughly one-third of the edible parts of food produced for human consumption gets lost or wasted globally. This amount accounts for about 1.3 billion tn/year and reflects not only the food processing wastes, but also the “food losses” (Gustavsson, Cederberg, Sonesson, van Otterdijk, & Meybeck 2011; in Galanakis 2012). Even though the sheer scale of available raw material makes for an attractive business potential, recovered materials often receive a higher degree of scrutiny, which results in partial loss of product functionality. Experience has particularly shown that a project focused on recovery technologies without investigating and establishing definite targeted applications of the final product, is doomed to fail (Galanakis 2012).

Key factors determining the optimal use of biomass waste are the conversion efficiencies of technologies and the kind and quantity of fossil products that can be substituted (Steubing et al. 2012). **It is critical to understand that using any resource, even if it appears to be available in excess, can have complex downstream effects on markets, other uses, and the demand for other resources** (Searle and Malins 2013). The average citizen in the European Union produces almost 500 kg of municipal waste per year. Less than half is processed in either recycling or composting, whereas over 30% of that rubbish occupies landfills constituting an ecological threat that has a serious impact on our environment, especially through methane emissions which are much more climate active than CO_2. Even with robust and effective policy support, some fraction of this resource is likely to be impossible to economically mobilize—the stronger the support framework, the more could be achieved (Searle and Malins 2013).

For example, the total amount of paper, wood, food, and garden waste produced in the EU is considerable. If all the EU-based sustainably available cellulosic biomass was processed for transport fuel, and accounting for energy losses in conversion, these renewable feedstocks could potentially displace 13% of road fuel consumption in the EU in 2020, and 16% in 2030. Once more, it is critical to keep in mind that using any resource, even if it appears to be available in excess, can have complex downstream effects on other markets, other uses, and the demand for other resources (Searle and Malins 2013).

[88] http://www.agriforvalor.eu/pages/home

5.2.1.2 Environmental impacts

Alongside the economic benefits, the advanced management of available carbon containing wastes and residues could help to reduce the use of petrochemicals, virgin materials and finite resources worldwide. This could contribute to reducing global carbon emissions and to increased sustainability and energy security (Hancock 2015). However, a large fraction of this is not truly "waste," but low-value input materials from industrial processing and livestock care. Diversion of these materials from their current uses would have potentially negative knock-on effects on industries and the environment (Searle and Malins 2013).

Residual biomass is only seldom purely waste and regularly fulfils other functions, such as maintaining soil quality or providing habitats. The benefits of extracting residual biomass for new applications, thus causing a resource use change (RUC), have to outweigh the loss of their former function. Not all residual biomass uses contribute to sustainability equally. Applications should be optimized to achieve various sustainability goals (Pfau 2015).

When it comes to residual biomass for energy, provided that heat can be used efficiently, optimizations for different environmental indicators almost always indicate that woody biomass is best used for combined heat and power generation, if coal, oil, or fuel oil based technologies can be substituted. However, **all biomass uses yield environmental benefits in a similar range as long as coal or oil based technologies can be substituted** (Steubing et al. 2012).

Cascading is an important option that deserves attention in the quest for deciding the approach that needs to be taken to achieve an efficient and sustainable bio-based economy. Several cascading concepts include cascading in use, in time and in function. The total CO_2 benefit from biomass cascading utilisation can amount to around 30% of the target emission reduction of 2,235 Mton CO_2 per year in the EU in 2030, relative to current emission levels (Odegard et al. 2012).

5.2.2 Discussion and identification of gaps

Current efforts on under-exploited wastes and technologies focus on improved green methods to reduce waste volume (EFIB 2015). However, when no further waste savings can be achieved, policy aspects seem to play a major role in ensuring these disruptive technologies can be successfully exploited (EFIB 2015). Positive impacts can be achieved under a clearer reframing of waste as by-product and focus on cascading. Nonetheless, any resource use change can have inadvertent consequences.

A number of policy conclusions can be drawn from the studies:

Measures could be taken both to remove barriers and to facilitate the growth of a waste industry (HoL, Science and Technology Select Committee, 2014).

Firstly, the policy needs to be in place to use waste as a resource – a solution here is to classify everything as a by-product and then have to reach a number of criteria before classifying it as a waste, rather than the other way around (EFIB 2015).

Also, normalising legislation and standardisation over Europe would greatly aid the foundation of markets, e.g. setting up bio-based tax incentives for production of bio-based materials (EFIB, 2015). Responsibilities should not be spread between too many ministries.

Knowledge on waste streams needs to be improved (HoL, Science and Technology Select Committee, 2014).

Finally, waste policy should not only consider environmental aspects, but also economic opportunities. The importance of long-term planning and strategy cannot be stressed enough. This can

reduce the risk of investment in this emerging industry is also essential (HoL, Science and Technology Select Committee, 2014).

Making use of waste and by-products is often depicted as the panacea for resource efficiency, reducing GHG emissions and overall environmental improvement. The studies show that there is tremendous potential concerning the availability of waste, however, several gaps still exist:

First of all, there is no consistent concept of how waste could be made more accessible. The implementation of central biowaste collection, for example, is still lacking in many EU member states. Also, the utilisation of agricultural residues would present great logistical challenges, making the whole endeavour probably much less economically feasible. There is no study assessing this – e.g. through case studies – on a European level. On top of that, the environmentally crucial role of such residues should not be underestimated. This is mentioned in several studies, but often lacks quantification (what does this exactly mean for waste availability? How much of which kinds of residues do we need to leave on the field? Are there regional differences?). Ronzon et al. 2015 found that there are still significant insecurities in calculating the availability of agricultural residues.

6 European, national and regional policies

Table 25: Studies relevant to the bioeconomy policy framework

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	Priority Recommendations[89]	LMI Ad-hoc Advisory Group for bio-based products, 2011	Concluded the work of the Ad Hoc Advisory Group for bio-based products which was initiated in 2008 in the framework of the Lead Market Initiative. Gives recommendations in five areas: • Access to feedstock • Research, development, innovation • Access to markets • Public procurement • Communication	These recommendations were the baseline for several EU policy initiatives, especially in standardisation as well as pre-standardisation, labelling and procurement research.
2	The third Industrial Revolution	Fischler, F. 2012	Makes the case for a shift away from fossil fuels towards a bioeconomy but stresses the non-level playing field between materials and energy. Highlights that the climate goals and other policy goals can very well be reached with material uses of biomass, too. Recommends to incentivise the shift towards more bio-based materials by refunding production costs linked to avoided GHG emissions, which would also level the playing field between different uses of biomass.	in: Biofuels, Bioprod. Bioref. 6:8-11 (2012)
3	Overview of Policy Measures for Biobased Products	Wydra, S. 2012	Gives an overview of some policy measures for supporting bio-based materials in six countries (US, Canada, Germany, France, China, Thailand), sorted by a) Support for R&D b) Support for Demonstration Activities c) Support for Commercialisation d) Demand-side policies	Slightly outdated, does not mirror the status quo anymore
4	What Europe has to offer biotechnology companies	EuropaBio / Ernst & Young, 2012	Excellent overview of relevant regulatory issues in Europe pertaining to (bio-)pharmaceutical industries, agricultural biotech products and industrial biotechnology. In-depth country-by-country analysis of regulatory and financial framework for companies planning to invest in biotechnology.	Very comprehensive overview and analysis, could be relevant to attract biotech companies to Europe. Might

[89] https://biobs.jrc.ec.europa.eu/policy/2011-lead-market-initiative-lmi-biobased-products-priority-recommendations

				be slightly out-dated, though.
5	Bioplastics: A Case Study of Bioeconomy in Italy	Ganapini, W., 2013	Explains the legislative measures taken in Italy to ban non-biodegradable disposable plastic bags and puts them in an environmental context. The two-pronged strategy of promoting re-usable plastic bags and biodegradable disposable bags is supposed to a) reduce waste, b) facilitate the recovery of household and packaging waste through organic recycling (which makes up for 12% of Italy's waste recovery) and to c) improve the quality of the organic waste fraction.	Very one-sided and Novamont-focused.
6	Biofuels – At What Cost? A review of costs and benefits of EU biofuels policies[90]	GSI (Global Subsidies Initiative) and iisd (International Institute for Sustainable Development) 2013	Assesses whether the biofuels policy of the EU is a cost-effective means to support the stated policy goals increased energy security, improvements in environmental performance and the generation of additional economic value. It concludes that the biofuels policy has been either an expensive or an ineffective way of reaching the goals. A much more economical and viable alternative would be tightening the emission standard for passenger vehicles.	
7	Market Developments of and Opportunities for biobased products and chemicals[91]	Dammer, L., Carus, M., Raschka, A., Scholz, L., 2013	Contains a chapter on policy, comparing amount of support measures for bioenergy and biofuels to the worldwide implemented support measures for material uses of biomass. Gives some recommendations on how the Netherlands could influence the policy landscape in order to create a level playing field for bio-based materials.	nova report written for NL Enterprise Agency

[90] https://www.iisd.org/gsi/sites/default/files/biofuels_subsidies_eu_review.pdf
[91] http://bio-based.eu/downloads/market-developments-opportunities-biobased-products-chemicals/

8	Biobased Chemicals and Bioplastics. Finding the right policy balance.[92]	OECD, 2014	This report examines the reasons why governments may wish to look at their policy balance and consider treating bio-based materials production similarly to fuels and electricity applications. It stresses that the demand for chemicals and materials will increase much more strongly than the one for energy, increasing the competition for oil; and that bio-based chemicals and materials offer at least the same climate mitigation potential as bio-based energy products. The report recommends to extend some policy measures used for biofuels to cover also bio-based materials (quotas/mandates; tax incentives; public procurement and regulatory policies) and it recommends phasing out fossil fuel subsidies in combination with carbon pricing.	Very comprehensive report; addresses many issues and makes a true effort at a balanced approach
9	Proposals for a Reform of the Renewable Energy Directive to a Renewable Energy and Materials Directive (REMD)[93]	Carus, M., Dammer, L., Hermann, A., Essel, R. 2014	The reform proposal aims at creating a level playing field for bio-based chemicals and materials with bioenergy and biofuels in Europe. It calls for an opening of the support system to also make bio-based chemicals and materials accountable for the renewables quota of each Member State. it proposes that the material use of a bio-based building block such as bioethanol or biomethane should be accounted for in the renewables quota the same way as it counts for the energy use of the same building block, e.g. fuel. Other building blocks, such as succinic acid, lactic acid, etc. could be accounted for based on a conversion into bio-ethanol equivalents according to their calorific value. Reduction of greenhouse gas emissions could also be the basis for such a conversion. Six more evolutionary proposals complement this comprehensive idea of a REMD.	nova study; innovative approach to the level playing field discussion.
10	Future of the European Fores-Based Sector and Bioeconomy – Policy Brief[94]	European Forest Institute, 2014	Stresses the transformations happening in the European forest sector away from traditional value chains such as pulp and paper towards innovative sectors such as chemicals, pre-fabricated wood products and textiles. Policy recommendations are to allow for the high diversity of the European forest sector (coverage of forest, ownership structures) and to have resource efficiency and sustainability as the basis for policy decisions.	
11	Options for Designing a New Political Framework of the European Biobased Economy[95]	Carus, M., Dammer, L., Essel, R. 2015	Paper discusses different push & pull mechanisms and their potential influence on the EU bioeconomy markets. Key recommendations are keeping the existing infrastructure of biofuels but substantially modifying the RED; using mandates and bans to create environmentally friendly innovation; not limiting R&D activities to specific biomass and applications only (e.g. being open to 1st generation) and guaranteeing the supply security of high value industries.	nova paper #6 on bio-based economy

[92] http://www.oecd-ilibrary.org/science-and-technology/biobased-chemicals-and-bioplastics_5jxwwfjx0djf-en
[93] http://www.nova-institut.de/download/nova-paper-4-remd
[94] http://www.efi.int/files/attachments/publications/efi_wsctu_6_2014.pdf
[95] http://bio-based.eu/downloads/options-designing-new-political-framework-european-bio-based-economy-nova-institutes-contribution-current-debate-2/

12	Balancing the bioeconomy: supporting biofuels and bio-based materials in public policy	Jim Philp, 2015	Proposes a public policy design for bioeconomy that respects cost effectiveness, openness to innovation and environmental friendliness while building on the idea developed by Carus et al. 2014. Bio-based chemicals should be able to receive support based on the existing support level for bioethanol as fuels (all chemicals can be calculated as bioethanol equivalents), but combined with GHG emission savings, production volumes and production efficiencies.	in: Energy & Environmental Science
13	The role of biomass and bioenergy in a future bioeconomy: Policies and facts[96]	Scarlat, N., Dallemand, J-F, Monforti-Ferrario, F., Nita, V. 2015	Mentions all policy papers and strategies on EU level relevant for a bioeconomy without analysing their impacts. Areas mentioned are: General bioeconomy strategies; energy and climate; agriculture, fisheries and forestry; industry; R&D; funding opportunities.	in: Environmental Development 15 (2015) pp 3-34.
14	Bioeconomy Policy. Synopsis and Analysis of Strategies in the G7[97]	German Bioeconomy Council, 2015	A review of the bioeconomy strategies of the G7 states Canada, France, Germany, Great Britain, Japan and USA (and EU). It concludes that there is a great variation in the political aims and measures of the individual countries. They are characterized by the prevailing industrial and economic profiles of the countries and by the amount of resources they have, especially by their natural resources potentials. Their underlying motivations range from a desire to secure access to raw materials through to comprehensive regeneration of the innovation system and the ecological transformation of the economy.	
15	Mid-term evaluation of the Renewable Energy Directive (RED). A study in the context of the REFIT programme[98]	Kampman et al. 2015	The following measures of the RED are found to be effective and efficient: Targets and measures, NREAPs, RES in transport biofuels and bioliquid sustainability and double counting. The effectiveness and efficiency of the remaining provisions was not yet assessable, due to either lack of data, delays in MS implementation or limited use of the provision so far (e.g. cooperation mechanisms, administrative procedures, RES in buildings, heating; Information, certification, training, etc.)	

[96] http://www.sciencedirect.com/science/article/pii/S2211464515000305
[97] http://bioeconomia.agripa.org/download-doc/64046
[98] https://ec.europa.eu/energy/sites/ener/files/documents/CE_Delft_3D59_Mid_term_evaluation_of_The_RED_DEF.PDF

16	Quo vadis, cascading use of biomass?[99]	Carus, M., Dammer, L., Essel, R. 2015	Paper highlights the benefits of an already existing commitments to cascading use; it analyses how the current political framework incentivises the direct energetic usage of biomass over a cascading use and provides an overview of the current debate pro and con cascading use (e.g. related to feedstock availability, climate targets, energy security). Lastly it presents a survey among industry experts on perceived hurdles and barriers for cascading use.	nova publication
17	The bioeconomy enabled. A roadmap to a thriving industrial biotechnology sector in Europe.[100]	BIO-TIC project, 2015	Roadmap gives ten key recommendations of how to pave the way for the industrial biotechnology sector in Europe. Concerning policy, it notes that a number of sectorial policies and funding mechanisms that have been put in place to support the development of industrial biotechnology and the bioeconomy still exist, to an extent, in isolation from one another. The report also recommends to provide financial incentives for bio-based chemicals and materials, either based on their share of bio-based content or on GHG emission reductions or other sustainability criteria. Another recommendation is to support public procurement of bio-based products.	
18	Final report: Working Group on Evaluation of the Implementation of the Lead Market Initiative for Bio-based Products' Priority Recommendations	Commission Expert Group for Bio-based Products, 2015	The Expert Group worked from 2013 to 2015 to assess the extent to which the priority recommendations of the LMI Ad-hoc Advisory Group for Bio-based Products of 2011 (report #1 in this list) were implemented. It concludes that • Serious action has been taken and results are visible regarding recommendations focused on Research, Development & Innovation, Public Procurement and Communication • Limited action has been taken and few results are visible regarding recommendations focused on Access to Feedstock and Access to Markets for bio-based products	Very helpful overview of state of play regarding policies specifically targeted to bio-based products
19	Sustainable Agriculture, Forestry and Fisheries in the	4th SCAR Foresight Exercise, 2015	Study assesses different scenarios of bioeconomy development from an agriculture, forestry and fisheries perspective. In terms of policy it stresses the need for evidence-based decision making that takes into consideration resource efficiency, circularity/cascading use, diversity, and other	

[99] http://bio-based.eu/downloads/quo-vadis-cascading-use-of-biomass/
[100] http://www.industrialbiotech-europe.eu/new/wp-content/uploads/2015/08/BIO-TIC-roadmap.pdf

	Bioeconomy. A Challenge for Europe.[101]		sustainability aspects. The competition between energetic and material uses of biomass, exacerbated by the RED, is mentioned, too.	
20	Mapping Study on Cascading Use of Wood[102]	Dammer et al. 2016	Study evaluates the policy landscape of five EU countries (Finland, Germany, Poland, Spain, UK) and the US with a view on how cascading use is either promoted or hampered by regulation. Main influencing factors are the implementation of recycling legislation and infrastructure, abundance of resources in a country and bioenergy regulation.	Report published by WFF/Mondi
21	Cascading Use of Woody Biomass[103]	Olsson et al. 2016	The paper analyses the consequences of potential implementation of the cascading principle by looking at both historical cases of similar policies and current examples from Europe and North America. Conclusions suggest that there are clear risks that policy implementation of the cascading principle results in complicated legislative processes, especially pertaining to reaching agreement on the set of wood assortments that can be used for material purposes and which therefore should be excluded from energy use. Given the large and growing international trade in both bioenergy and biomaterials, further complications are likely to arise if the cascading principle is enforced only in select EU member states or in the EU but not in North America. Without harmonized rules, the efficiency and efficacy of cascading policies could be compromised as market actors focus more on exploiting regulatory loopholes than on improving their performance.	IEA Bioenergy Task 40
22	Unlock the potential of renewable, bio-based materials for a Circular Economy[104]	The Alliance for Beverage Cartons and the Environment, CEPF, cepi, copa cogeca, ELO, EuropaBio, Euro-	The statement calls for policy makers to acknowledge the potential of bio-based materials, since they replace finite materials with materials from renewable sources. Policy makers are encouraged to incentivise the use of bio-based materials when implementing the Commission's Action Plan and to especially support sectors, in which solutions are already existing (e.g. packaging).	Industry position paper, so strongly biased; but illustrates one coin of a very recent policy debate.

[101] https://ec.europa.eu/research/scar/index.cfm?pg=foresight4th
[102] http://wwf.panda.org/?263091/Cascading-use-of-wood-products-report
[103] https://www.dbfz.de/fileadmin/user_upload/Referenzen/Studien/t40-cascading-2016.pdf
[104] http://www.cepf-eu.org/vedl/Renewable, bio-based materials for a circular economy_April2016.pdf

		pean Bio-plastics, 2016		
23	Joint position paper: Bioplastics in a Circular Economy: The need to focus on waste reduction and prevention to avoid false solutions[105]	Surfrider Foundation Europe, Friends of the Earth Europe, Zero Waste Europe, ECOS, EEB, 2016	States that bioplastics are not a real solution for the plastics problem faced by our planet at the moment and should not be promoted as such and should not be unduly promoted by policy makers. Highlights the land use and other sustainability issues related to bioplastics. A Circular Economy should focus on waste reduction and prevention instead of taking ‘easy’ or ‘false’ solutions.	The other side of the coin of the debate around the sustainability of bioplastics and their role in a Circular Economy.

[105] http://www.eeb.org/index.cfm/library/joint-position-paper-on-bioplastics-in-a-circular-economy/

6.1 Key findings of the assessed studies

As can be seen from the long list of studies, policy is a widely discussed issue in the context of bioeconomy. Many more studies could be quoted that briefly touch policy in addition to their more technological or economic focuses. Since the focus is only on reports and studies, primary sources such as strategies or roadmaps published by Member States or the EU were not taken into consideration for analytical purposes. The BioSTEP project has compiled a comprehensive list of existing bioeconomy strategies, therefore this exercise is not copied here. The BioSTEP list is available under http://www.bio-step.eu/background/bioeconomy-strategies.html

Most studies agree that the bioeconomy is a cross-cutting issue which is influenced by a wide variety of policy areas. Scarlat et al. 2015 provide an excellent overview of all the policy documents determining the bioeconomy on EU level, sorted into the areas

- general bioeconomy strategies;
- energy and climate;
- agriculture,
- fisheries and forestry;
- industry;
- R&D;
- funding opportunities.

One interesting reading of this list could be that there is no dedicated policy on chemicals and materials – they are only inadvertently or at least indirectly influenced by the policy. The list, however, does not give any indication of the influence of the selected policy documents on activities within the bioeconomy. Other studies attempt these analyses and some re-occurring topics were identified during the analysis, which will be summarised below.

6.1.1 Level playing field

Probably the most prominent catch-phrase within the discussions about bioeconomy policy, "level playing field" refers to the political treatment of different usages of biomass. While food, feed, bioenergy/biofuels and bio-based materials are all part of the European bioeconomy, their specific policy frameworks are very different, both in quantitative as well as in qualitative terms. Dammer et al. 2013 compiled a comparison of existing support mechanisms for material uses on the one hand, and energy uses on the other, worldwide (see Table 26 and Table 27). The comparison shows that while for bioenergy and biofuels there is a comprehensive set of many different support mechanisms – many of them binding – in a large number of countries worldwide, there are almost none for the material sector. And if there are, they are often much weaker and more time limited than the existing policy tools for the energy sector.

Table 26: Support measures for material uses of biomass

Country \ Measure	Investment incentives	Mandates	Public procurement	Bans / Fees for conventional plastics
Thailand	x			
Japan		(x)[1]		
South Korea	x		x	x
Malaysia	x			
China	x			
Brazil	x			
US	x		x	x[2]
Canada				x
Netherlands			(x)[3]	
Germany			(x)	
Italy			(x)	x
Denmark			(x)	x
Bulgaria				
Israel				x
United Arab Emirates				x

Table 27: Support mechanisms for renewable energy, incl. bioenergy

● indicates national level policy ○ indicates state/provincial level policy	REGULATORY POLICIES AND TARGETS							FISCAL INCENTIVES				PUBLIC FINANCING	
	Renewable energy targets	Feed-in tariff premium payment	Electric utility quota obligation/RPS	Net metering	Biofuels obligation/mandate	Heat obligation/mandate	Tradable REC	Capital subsidy, grant, or rebate	Investment or production tax credits	Reductions in sales, energy, CO_2, VAT, or other taxes	Energy production payment	Public investment, loans, or grants	Public competitive bidding/tendering
HIGH INCOME COUNTRIES $$$$													
Australia	●	○			○		●	●				●	
Austria	●	●			●		●	●	●			●	
Barbados	●			●								●	
Belgium	●		○	○	●		●		●			●	●
Canada	○	○	○	○	●			●	●	●		●	●
Croatia	●	●						●				●	
Cyprus	●	●			●			●					
Czech Republic	●	●			●		●	●	●	●		●	
Denmark	●	●		●	●		●	●		●		●	●
Estonia	●	●			●						●	●	
Finland	●	●			●		●	●		●	●		
France	●	●			●		●	●	●	●		●	●
Germany	●	●			●	●		●	●	●	●	●	
Greece	●	●			●			●	●	●		●	
Hungary	●	●			●			●		●		●	
Ireland	●	●			●	○	●						●
Israel	●	●	●			●				●		●	●
Italy	●	●	●	●	●	●	●	●	●	●		●	●
Japan	●	●	●	●			●	●	●			●	
Luxembourg	●	●			●			●		●			
Malta	●	●		●				●		●			
Netherlands	●	●		●	●		●	●	●	●	●	●	
New Zealand	●												
Norway	●				●		●	●		●		●	
Oman								●			●	●	●
Poland	●		●		●		●	●		●		●	●
Portugal	●	●	●	●	●	●		●	●	●		●	●
Singapore				●								●	●
Slovakia	●	●						●		●			
Slovenia	●	●						●					●
South Korea	●		●	●	●		●	●	●	●		●	
Spain[1]	●	●		●	●	●		●	●	●		●	
Sweden	●		●		●		●	●	●	●		●	
Switzerland	●	●						●		●			
Trinidad and Tobago	●								●	●			
United Arab Emirates	○		○			○					○	○	○
United Kingdom	●	●	●		●	●	●	●		●	●	●	
United States		○	○	○	●	○	○	●	●	●	●	●	●

Source for both tables: Dammer et al. 2013

Several authors have discussed the impacts of this imbalance, stating e.g. higher costs and restricted access to biomass for material uses due to artificially high prices caused by the support system. As the OECD put it in their 2014 report:

> "On the policy front, it has been obvious for several years that there is a vast network of public policy support mechanisms for biofuels, involving subsidies across the entire value chain from biomass to byproducts of the production process. The recent boom in bioenergy, involving the use of wood pellets to fuel power stations, has also benefited from a great deal of policy support. In comparison, the support given to bio-based chemicals and

> plastics has been minimal. This makes policy geared towards integrated biorefining unbalanced."

This is in contrast to the commonly agreed on fact that demand for chemicals and materials will increase much more strongly than that for energy in the future and that bio-based materials offer the same or more GHG emission savings as the use of bioenergy. It should be noted that several competitor countries, especially Asian ones such as Malaysia, Thailand or China have implemented investment incentives, e.g. in the form of tax exemptions for new biotechnology or bio-based companies to set up their business. This is one of the reasons why in the last several years, investment has been carried out more and more in competitor regions and not in the EU (for more details, please have a look at the investment chapter).

Despite this more or less accepted fact of an existing non-level playing field with its resulting negative impacts, few authors have made suggestions on how this could be addressed. Exceptions are Carus et al. 2014 and Philp 2015, with the latter further developing the idea presented in Carus et al. 2014: Bio-based chemicals should be able to receive support based on the existing support level for bioethanol as fuels (all chemicals can be calculated as bioethanol equivalents), but combined with GHG emission savings, production volumes and production efficiencies.

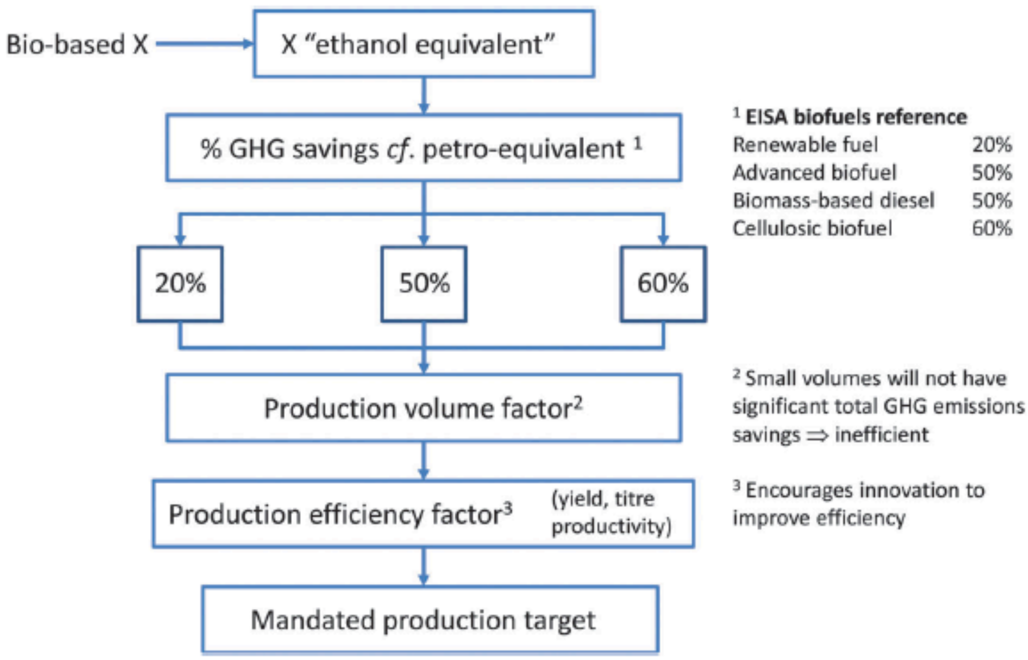


Figure 39: Schematic description of a fair support system for bio-based materials and energy, taking into account cost effectiveness and GHG emission reductions
Source: Philp 2015

The current discussions around the Renewable Energy Directive post-2020 do not take any such proposals under consideration. The feedstocks still listed in Annex IX of the Commission Proposal of November 2016 – or at least some of them – are in demand from both the energy and the industrial material uses. The current outline still treats them as if there was no competition for them and they were just wastes (even if the word is avoided now) lying around, for the energy sector to finally make use of, which is not the real situation.

6.1.2 Market access of bio-based products

Another widely debated issue – and closely related to the level playing field – is how policy can and does influence the market access of bio-based products. In general, it is not easy in the European Union to design regulation in a way that certain products are favoured over others, since this constitutes unfair competition and can be prosecuted. There are some exceptions for environmentally friendly products, e.g. the possibility to allow reduced Value Added Tax for such products.

The LMI Ad-hoc Advisory Group on bio-based products made three key recommendations concerning access to markets in 2011:

- Continue to develop and apply clear and unambiguous European and international standards. The standards help to verify claims about bio-based products in the future (e.g. biodegradability, bio-based content, recyclability, and sustainability).
- Consider setting indicative or binding targets for certain bio-based product categories where they contribute towards achieving the objectives of existing and future sustainability policies (such as climate change, resource efficiency, energy security, etc). Study their market perspective, possible mechanism for implementation and their contribution to these sustainability goals.
- Allow Member States to grant tax incentives for sustainable bio-based product categories.

From 2013 to 2015, the Commission Expert Group for Bio-based Products evaluated the progress made in implementing these recommendations. While the steps taken towards standardization and certification were rated positively – the only gap being actual usage of the standards by companies to declare their products and by governments for the setting of incentives –, both recommendations targeting ‘stronger’ market tools, i.e. targets and tax incentives, were found to be lacking in levels of implementation. On indicative targets, the expert group wrote:

> Although certain discussions at a European level and in some member states are taking place, no real achievements have been observed. […] A political consensus cannot currently be perceived. Any implementation still seems remote.

And regarding tax incentives, the conclusion read:

> Tax incentives are being seriously discussed at EU level. Some member state already use tax incentives to support bio-based and/or environmental products such as France, Italy, UK, The Netherlands and Belgium. […] For tax issues duties and responsibilities lie first and foremost with the Member States so the scope of action at an EU level is naturally limited. Prospects of implementing this recommendation by all Member States still seems to be remote. (Commission Expert Group 2015)

In Germany, for example, the current VAT situation favours wood being sold for energy purposes (7% VAT) over wood being sold for any other purposes (19% VAT). So instead of giving tax incentives to solid wood products (which store carbon over their life time and can be recycled many times), it even hampers its market chances. This unfair situation mirrors both the non-level playing field as well as issues revolving market access.

Carus et al. 2015 provide an overview of potential instruments for improving market access of bio-based products, sorted into push & pull instruments:

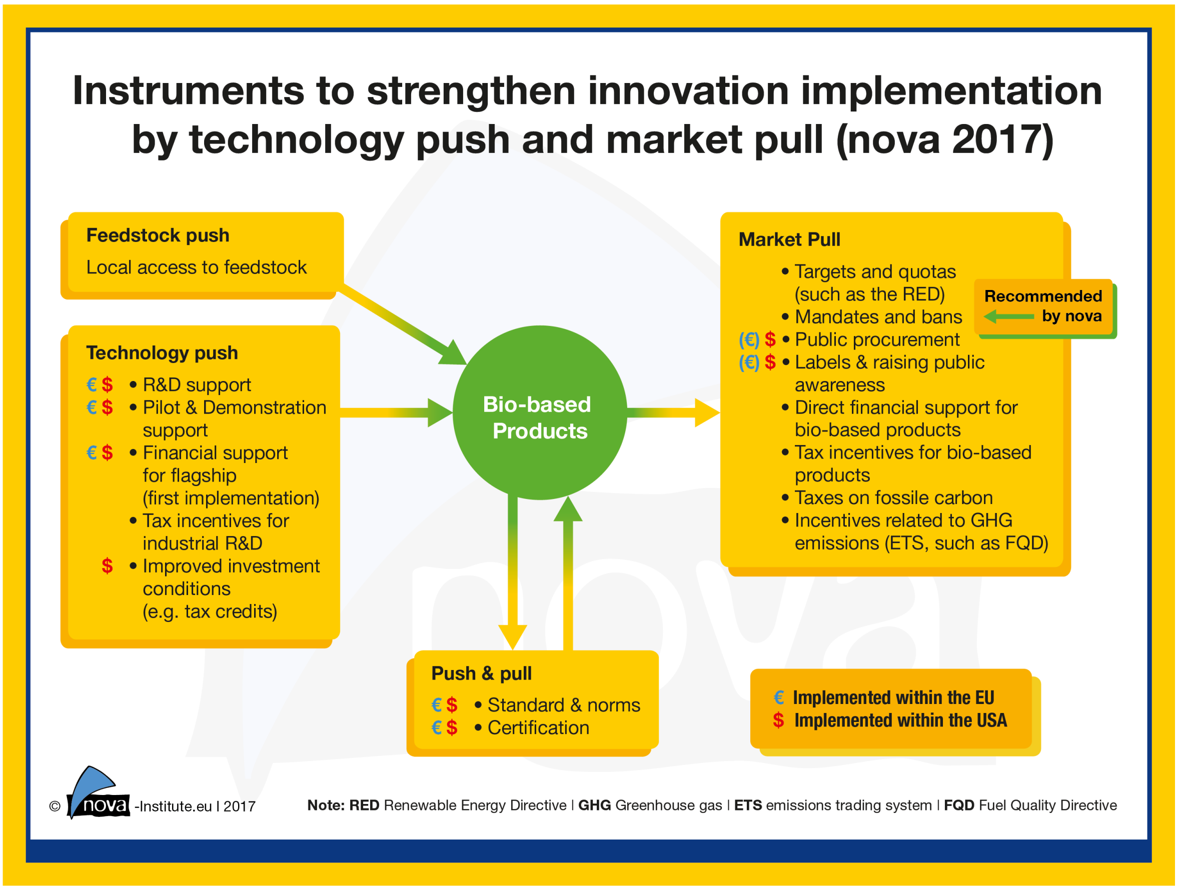


Figure 40: Push and pull instruments for improved market access of bio-based products
Source: Carus et al. 2015

Some of the stronger – and therefore recommended by nova – measure listed in the paper read:

> Use mandates and bans to create environmentally friendly innovation.
>
> Mandates and bans should be used as strong instruments based on sound environmental and health reasons in order to tap the full positive potential of bio-based products. The reason for the mandates and bans is not, that the products are bio-based, but that the products have superior functionalities and properties concerning environmental and health.
>
> These market pull measures should be implemented in close coordination with a technological push in the form of support for R&D, pilot and demonstration plants and flagship investments, in order to get those technologies and products off the ground for which a sufficient market pull and demand exists.
>
> Examples are plasticizers for plastics without impacts on the hormone system, detergents with fast biodegradation in waste water streams or biodegradation for specific plastic applications which cannot collected and recycled.
>
> So increasing the environmental and health requirements will support the market penetration of bio-based products a long lasting way, not depending on any bio-based specific incentives.

> Enhanced product liability: If you place products in the environment that cannot be collected, separated and recycled, they must be biodegradable in the appropriate environment.

6.1.3 Cascading use, circularity, biodegradability

Especially among more recent publications (2014 onwards), the topics of cascading use and circularity have become more prominent in the context of the bio-based economy. While cascading use became a real 'buzzword' for some time, there were also some concerns connected to it. First and foremost, it is not easy to define cascading use, and often the term is used both for sequential usages of the same material for different applications after the end of one application's lifetime as well as for the parallel use of different fractions of one feedstocks for separate applications (this is also often called "coupled production"). Dammer et al. 2016 in their report for the Worldwide Fund for Nature (WWF) and Mondi summarised this discussion and made an attempt to establish a more widely accepted definition of cascading use, based on previous research and publications:

> Cascading use of biomass takes place when biomass is processed into a bio-based final product and this final product is utilised at least once more either for material use or energy. Furthermore, the study differentiates between single stage cascades (when biomass is used once as a final product and then used for energy) and multi-stage cascades (if biomass is subsequently used for several material applications before it is used for energy).[106]

The study concluded that none of the investigated countries had dedicated policies on cascading use of wood. However, a multitude of policies and legislative measures influence cascading use and the wood sector in general, e.g. bioeconomy strategies, forestry management, waste policy, bioenergy policy, building regulations, etc. One of the major findings of the study was that **the existence of a stable wood recycling framework has the strongest positive influence on cascading quotas, while the existence of bioenergy incentives was found to have the strongest negative influence.** Obviously, wood cannot be recycled and used in other applications if it is incinerated right away. It should be mentioned that cascading use is not always the best option in overall resource efficiency, since recycling takes resources for transport and processing. However, with a view on how efficiently the biomass itself is utilised, bioenergy incentives have a significant negative impact. In this light, it is interesting to note that Olsson et al. 2016, speaking for the IEA Bioenergy Task 40, urge extreme caution when talking about policy measures "enforcing" cascading use, warning about complicated policy frameworks with unintended side effects. Promoters of the cascading idea would argue that without the policy measures "enforcing" bioenergy usage, cascading uses would become more attractive, due to higher value creation from the same feedstock. The literature on cascading use needs to be interpreted with some caution, depending on the vested interest in feedstock supply by different parties.

Cascading use becomes especially interesting in the context of a circular economy, since it fulfils the exact objective of using a material again after its first end of life, instead of discarding it right away.

[106] It should be noted that this definition implicitly excludes coupled production or the mere use of side-streams from being called "cascading use". However, in a lot of publications, this is still done and included, e.g. in the cascading study carried out for the Commission in 2016, which was not included in the focus of this analysis since it does not have a strong policy focus for the whole bio-based economy.

Another issue related to bio-based products often discussed in the context of the circular economy is biodegradability as end of life option. Discussing all misunderstanding around biodegradability and how it applies to bio-based products is beyond the scope of the paper, but it becomes a problem when biodegradability is presented as a panacea to waste in general and to marine littering specifically. Publications #21 and #22 in the list show the conflicts around these issues quite well. While one presents the views of industry associations that give a somewhat one-sided and general depiction of their products, the other gives the opinion of several environmental NGOs. It should be noted that both papers are lacking in scientific evidence and need to be treated carefully if taken as a basis for policy making. Choosing the best end of life options for certain applications in specific environments is tricky, and setting the appropriate framework conditions is a difficult task for policy makers. **It is of utmost importance that more scientific evidence is collected when designing the implementation of the Circular Economy package, i.e. through the Plastics Strategy.**

6.1.4 Public procurement

Due to its significant spending power, public procurement has been in the focus of bio-based policy recommendations revolving market access for quite some time, too. In 2011, the LMI Ad-Hob Advisory Group recommended to

- Encourage contracting authorities in all EU Member States to give preference to bio-based products in tender specifications. A requirement or a recommendation to give preference can be laid down in a national action plan adopted by the government. Preference should be given to bio-based products unless the products are not readily available on the market, the products are available only at excessive cost, or the products do not have an acceptable performance.

- Develop a list of product groups and designated bio-based products. The product groups and subgroups reflect the areas of application (e.g. building materials, furniture, cleaning products, lubricants, packaging, etc). The designated bio- based products reflect the individual products from each manufacturer respectively.

These recommendations are closely oriented at the "BioPreferred" Program in the US. As of now, both recommendations have not really been implemented on a EU level. While some Member States have started pilot projects on bio-based procurement, there is no binding preference for bio-based products and no official EU sanctioned product list (Commission Expert Group 2015). At a workshop carried out by the Commission Expert Group Working Group for Public Procurement (WG PP) in 2016 also revealed that while the experts of the bio-based economy had drafted some nice recommendations, experts from public procurement saw high barriers towards achieving a widely-accepted bio-based procurement. These are both rooted in public procurement law as well as practice. Therefore, significant commitment and resources are still required to make progress on this topic.

6.2 Discussion and identification of gaps

There is a large number of studies, reports and expert papers on policy issues around the bio-based economy. A gap can therefore not really be seen in the general amount of research, but rather in the implementation and political commitment and willingness to follow up on recommendations.

One exception however, is the evidence base around the nexus of biodegradability, best end-of-life option and policy design for plastics in a Circular Economy. Further research is needed to inform policy making on this issue.

7 Research and technologies

Table 28: Studies relevant to research, technologies and biorefineries

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	Medium and Long-term Opportunities and Risks of the Biotechnological Production of Bulk Chemicals from Renewable Resources - The Potential of White Biotechnology	Patel, M., et al. 2006	This report studies processes which convert biomass-derived feedstocks (e.g. fermentable sugar) into organic bulk chemicals (e.g., lactic acid, acetic acid, butanol and ethanol) by means of White Biotechnology, i.e. by fermentation or enzymatic conversion, either with or without genetically modified organisms. Apart from White Biotechnology, also conventional chemistry is involved in all processes. All White Biotechnology products are compared to functionally equivalent petrochemical products. The key results of this comparison are • White Biotechnology for bulk chemicals production is primarily an economic challenge • It offers very substantial opportunities for the chemical industry to reduce their non-renewable energy use, greenhouse gas emissions and related environmental impacts. • Conventional risks of biotechnologically produced chemicals (risks related to genetically modified micro-organisms and crop plants excluded) are comparable to those of chemicals derived from fossil fuels); • Stakeholders and the public seem to have a basically positive attitude towards organic chemicals made from White Biotechnology, with environmental considerations and the use of renewable raw materials primarily determining this perception. The report concludes that the four core requirements must be fulfilled in order to make clear steps towards bio-based chemical industry • Substantial technological breakthroughs must be realized in the bioprocess step.	The BREW Project[107]; out of scope timewise but milestone study

[107] http://brew.geo.uu.nl/BREW_Final_Report_September_2006.pdf

			• Major progress must be made in downstream processing. • Prices for fossil fuels must be high. • Prices for fermentable sugar must be low.	
2	Roadmap Bioraffinerien im Rahmen der Aktionspläne der Bundesregierung zur stofflichen und energetischen Nutzung nachwachsender Rohstoffe	Federal Government of Germany, 2012	This roadmap of the German government focusses on a strategy to implement biorefineries in the research and development plan in Germany and is based on the research strategy called "Nationale Forschungsstrategie BioÖkonomie 2030". The idea behind is to expand and optimize the use of biomass and other renewable resources to produce bio-based products in Germany. Beside a description of the different types of biorefineries (based on the feedstocks) and the state of the art with SWOT analyses of several types of biorefineries. This report concludes that biorefineries are on a way to play an important role in the development for an efficient way to use biomass and to substitute a range of petroleum-based chemicals, fuels and materials in future. It also states the need for further research in this area and the willingness of the German government to support these needs in the future research strategies.	In German[108]
3	National Plan for Industrial Biotechnology Towards a Greener, Cleaner 2025	Chemical Sciences Scotland, 2012	This National Plan for Industrial Biotechnology is an overview of results from extensive consultation with the businesses, academic and research institutions as well as the Scottish and UK governments and their agencies. This reports draws conclusions on how Scotland can make best use of Scotland's existing strengths in chemical, life sciences and engineering and how they can take advantage of the country's academic and research expertise while also identifying important activities which will help them and out partners meet their objectives for IB in Scotland.	Life Science Scotland[109]
4	The Role of Catalysis for the sustainable production of Bio-fuels and Bio-Chemicals	Antafylids, K., Lappas, A., Stöcker, M., 2013	This book comes to fill the gap of the potential of catalysis in the valorisation of biomass or its primary conversion products, such as bio-oil, lignin, and carbohydrate. The focus is on the "role of catalysis in the production of biofuels and bio-chemicals." Emphasis has been placed on the mechanistic understanding of the catalytic processes, the dependence of activity/selectivity on catalyst's structure, porosity,	ELSEVIER[110]

[108] http://www.bmel.de/SharedDocs/Downloads/Broschueren/RoadmapBioraffinerien.pdf?__blob=publicationFile
[109] https://www.ibioic.com/files/media/National_Plan_for_Industrial_Biotec.pdf
[110] http://www.sciencedirect.com/science/book/9780444563309

			acidity, basicity, metal-support interactions, particle morphology, hydrothermal stability, and resistance to deactivation. The important issue of scaling-up of new catalytic processes has also been considered, as it sometimes can be a major obstacle toward industrial development and application. The conclusions made in this book are as many as the chapter were discussed technology wise. The key ones are the developments in
			
			• Catalytic Upgrading of Fats and Vegetable Oils for the Production of Fuels
			• Heterogeneous Catalysis for Biodiesel Production
			• Catalytic Pyrolysis of Lignocellulosic Biomass
			• Pathways and Mechanisms of Fast Pyrolysis: Impact on Catalyst Research
			• Role of Acid Catalysis in the Conversion of Lignocellulosic Biomass to Fuels and Chemicals
			  • Integrating White Biotechnology in Lignocellulosic Biomass
			  • Transformations: From Enzyme-Catalysis to Metabolic Engineering	

5	Current progress on bio-based polymers and their future trends	Babu, R., O'Connor, K., Seeram, R., 2013	This article reviews the recent trends, developments, and future applications of bio-based polymers produced from renewable resources. Polymers in several applications but also provide new combinations of properties for new applications. A range of bio-based polymers like PLA, PHA, PBS or bio-based polyethylene are presented in this review, focusing on general methods of production, properties, and commercial applications. The review examines the technological and future challenges discussed in bringing these materials to a wide range of applications, together with potential solutions, as well as discusses the major industry players who are bringing these materials to the market. It concludes that bio-based polymers are closer to the reality of replacing conventional polymers than ever before. Nowadays, bio-based polymers are commonly found in many applications from commodity to hi-tech applications due to advancement in biotechnologies and public awareness. However, despite	Progress in Biomaterials December 2013, 2:8 (Springer)[111]

[111] http://link.springer.com/article/10.1186/2194-0517-2-8

			these advancements, there are still some drawbacks which prevent the wider commercialization of bio-based polymers in many applications. This is mainly due to performance and price when compared with their conventional counter-parts, which remains a significant challenge for bio-based polymers.	
6	Deutscher Biotechnol-ogie-Report	Bialojan, S., 2013	The 14th edition of the German Ernst & Young Biotech report attempts to widen again the perspective which had been narrowed down in previous years to more and more reflect individualized aspects – such as USPs, individual business plans or opti-mized financial strategies. It is about new opportunities in a changing environment with specific emphasis on applications in multiple industries. Also deals with the is-sue of extracting value from biotech capabilities. In several portraits and abstracts on different industry areas mainly in the pharmaceuticals the report reflects the frame-work of companies, clusters and organizations in the German Biotech area and re-flects their role in the overall picture. Numbers are shown to get an idea of the overall industry sector and on several special topics within the German Biotechnology indus-try.	Ernst & Young[112]
7	Handbook of com-mercial bio-based chemicals	Edited by Tecnon OrbiChem, 2013	Tecnon OrbiChem is producing monthly reports: ” Bio-Materials & Intermediates”, in the Chemical Business Focus series since September 2013. Each month they com-pile a profile on a particular chemical, that can be produced by both conventional and metabolic processes, comparing the different routes and commenting on the potential commercial viability of the bio-processes. Each profile is given the date of its compi-lation and readers should be aware that there may have been developments since that date. This handbook gives an overview on the current status of several bio-based chemicals like building blocks, platform chemicals and polymers. It shows prices, capacities and trends on these chemicals.	Commercial study

[112] http://www.de.ey.com/Publication/vwLUAssets/EY-Biotech-Report-2016-Im-Schatten-von-Leuchttuermen/$FILE/EY-Biotech-Report-2016-Im-Schatten-von-Leuchttuer-men.pdf

8	Systems perspectives on Biorefineries	Sandén, B., Petterson, K., 2014 (editors)	This report gives systems perspectives on bio-refineries in 2012; it contains nine chapters that address different topics related to how the world's biomass resources can, or should, be converted into the goods we need and desire. The technologies dicussed are the gasification and fermentation pathway and a range of possibilities in integrating biorefining in the process industry. In one chapter on "Market potential for biorefineries" (Janssen, M.) the report gives an overview of some of the products that can be manufactured using biorefinery concepts followed by a discussion. It concludes that the successful commercialisation and diffusion of these products do not depend on technical issues only. Besides production costs, market size and competition, also policy instruments affect the competitiveness of different products. For example, in many countries there are currently subsidies when biomass is used for biofuels and bioelectricity production, while this is not the case to produce green chemicals and materials. Moreover, the environmental impact of the production of biobased products needs to be considered, when assessing the future desirability of individual products. It is not guaranteed that all biobased products are more environmentally friendly than their fossil-based counterparts. Another chapter (Petterson, K., Grahn, M.) concentrates on the greenhouse gas effects and concludes that different studies can come to very different conclusions depending on the methodology. It shows several examples representing that substantial reductions of GHG emissions can be achieved by substituting fossil-based motor fuels with certain biofuels. However, biomass is a limited resource and it is not possible to solve the whole climate problem by substituting biomass for fossil fuels.	Chalmers University of Technology[113]
9	Biorefinery: The bridge between Agriculture and Chemistry	Sanders, J., 2014	This presentation outlines key drivers, challenges and the processes and products needed for The Netherlands to build an economically feasible bio-refinery. It discusses integration of corn and grass biorefineries to produce animal feed in the Netherlands. As conclusion it claims: • Biorefinery increases the value of the individual biomass components	Wageningen University, Presentation at the European Conference on Biorefinery Research, Helsinki,

[113] http://www.chalmers.se/en/areas-of-advance/energy/Documents/Systems Perspectives on/Systems_Perspectives_on_Biorefineries_2014_v3.1b.pdf

			• (Platform) chemicals can be derived from biomass under economic conditions. For the moment, functionalized chemicals offer the best chances to compete with petrochemical processes • Although our harbours can also export biomass components, our big harbours can benefit from the abundant agriculture abroad. • Small scale (pre)processing offers economic advantages and potential forward integration to the farmer	19 and 20 October 2006[114]
10	IEA BIOENERGY Task42 BIOREFINING	van Ree, R., van Zeeland, A., 2014	This triennium (2013-2015) Task42 report focused on tackling market deployment aspects for integrated bio-refineries, supporting stakeholders in the energy sector, finding their position within a future bio-based based Economy, assessing optimal sustainable use of biomass for Food and Non-food applications, and dissemination & training activities. Regarding sustainability aspects of biorefineries, it claims that a sustainability assessment should reflect the important renewability attribute in addition to showing how biorefineries contribute to social, environmental and economic well-being (or people, planet and profit). As much as possible, assessments should be carried out on a lifecycle basis, starting from biomass feedstock and extending to the end-of-life of the products derived from its biomass feedstocks. This is more easily carried out for biofuel-driven biorefineries, as fuels have relatively short value chains.	IEA Bioenergy[115]
11	Political Challenges for the Industrialization of the Bioeconomy including Biorefineries and Biobased products	Boenke, A,, 2014	The presentation reports about the projects for bio-refineries that have been carried out over the last few years in the European context. Examples of projects are • **EUROBIOREF** – fragmentation in the biomass industry • **BIOCORE** – lignocellulosic biorefinery for sustainable processing of agricultural residues • **SUPRABIO** – integrate novel intensified unit operations for the production of 2nd gen. Biofuels, intermediates and high value products	Presentation

114 https://ec.europa.eu/research/energy/pdf/gp/gp_events/biorefinery/bs4_01_sanders_en.pdf
115 http://www.ieabioenergy.com/wp-content/uploads/2014/09/IEA-Bioenergy-Task42-Biorefining-Brochure-SEP2014_LR.pdf

			• **PROSUITE** – PROspective SUstaInability Assessment of Technologies ***& linked to*** **LC-IMPACT - L**ife **C**ycle **I**mpact assessment **M**ethods for im-**P**roved sust**A**inability **C**haracterisation of **T**echnologies • **GLOBAL-BIO-PACT** – Global Assessment of Biomass and Bioproduct Impacts on Socio-economics and Sustainability • "**LCA to go**" – Boosting LCA Use in European SME	
12	International overview of biobased building block chemicals	IAR Cluster Experts-2014	The IAR Cluster has implemented a service of business intelligence (BI) intended to identify, analyse and disseminate information among the Cluster's members. This service draws on a collaborative intelligence platform, dedicated to bio-based chemistry. The tool includes more than 9,700 resources (patents, news, reports, and projects).	Commercial report[116]
13	VDI 6310 - Klassifikation und Gütekriterien von Bioraffinerien	Verein Deutscher Ingenieure (Association of German Engineers), 2014	The VDI 6310 is a norm on the classification and quality criteria of biorefineries of the Association of German Engineers (VDI). It mainly describes the different types of biorefineries and classifies the technical descriptions and technology concepts within this area. It describes biorefineries as important drivers of the development in the different areas within the industry for the production of food, feed, chemicals, fuels and energy. In this context, it also reflects the needs for economic, ecological and social criteria in the classification for biorefineries and in the future development and implementation.	
14	Techno-economic evaluation (TEE) of lignocellulosic biorefineries	Piotrowski, S., Carus, M., Sibilla, F., Raschka, A., 2014	A newly developed methodology for a TEE of bio-refineries and other complex bio-based processes with limited available data. Within Work package (WP) 1, nova calculated procurement costs for the different feedstocks up to farm gate/roadside specifically for the case study regions. The calculated costs were used by project partner Imperial College as input parameters for a supply chain model which calculated procurement costs up to the bio-refinery gate (including transportation, logistics and drying costs).	Part of the BIO-CORE project in the framework of FP7

[116] http://www.iar-pole.com/wp-content/uploads/downloads/2014/12/Sample-IAR-study-The-international-overview-of-bio-based-chemical-building-blocks.pdf

15	Strategic Innovation and Research Agenda	Sommer, K., 2015	This Strategic Innovation and Research Agenda (SIRA) explains the strategy and role of SusChem in the context of EU's growth strategy for the next decade that aims to transform the EU into a smart, sustainable and inclusive economy. It highlights a portfolio of sustainable chemistry research and innovation actions that the platform believes can make a significant contribution to improving competitiveness and sustainability, address societal challenges and contribute to achieving jobs and growth.	SusChem
16	From the Sugar Platform to biofuels and biochemicals	Taylor, R., Nattrass, L., , 2015	The study created a company database for 94 sugar-based products, with some already commercial, the majority at research/pilot stage, and only a few demonstration plants crossing the "valley of death". Case studies describe the value proposition, market outlook and EU activity for ten value chains (acrylic, adipic & succinic acids, FDCA, BDO, farnesene, isobutene, PLA, PHAs and PE). Most can deliver significant greenhouse savings and drop-in (or improved) properties, but at an added cost to fossil alternatives.	Final report for the European Commission Directorate-General Energy
17	Biodesign for the Bioeconomy UK Synthetic Biology Strategic Plan 2016	SBLC Members, Observers, Policy Advisors and Secretariat, December 2015	The paper describes how the UK aims to achieve a £10bn UK synthetic biology market by 2030, capable of delivering substantial societal and economic impact nationally and internationally. This paper advises that the UK must commercialize cutting-edge science and technology through a healthy innovation pipeline, a highly skilled workforce, and an environment in which innovative businesses can thrive. The paper concludes by saying that synthetic biology is capable of delivering new solutions to key challenges across the bioeconomy. It also goes on to conclude that synthetic biology delivers the capability to manufacture complex molecules that are currently very difficult, too expensive or simply impossible to produce. The potential value of synthetic biology is stimulating considerable interest around the world, and rapid progress continues to be achieved through collective global activity.	Synthetic Biology Leadership Council[117]

[117] https://connect.innovateuk.org/documents/2826135/31405930/BioDesign+for+the+Bioeconomy+2016+DIGITAL+updated+21_03_2016.pdf/d0409f15-bad3-4f55-be03-430bc7ab4e7e

18	A Roadmap to a Thriving Industrial Biotechnology Sector in Europe	Various Authors from the BIO-TIC team, 2015	The BIO-TIC project was a solutions-centred approach that comprehensively examined the innovation hurdles in industrial biotechnology across Europe and formulated action plans and recommendations to overcome them via a market, a technology and a non-technology roadmap. Aside from a holistic view on industrial biotechnology and its integration in various production pathways, the project concentrated on five business cases to represent product groups that can make a major contribution to an accelerated uptake of IB into the market place: Advanced biofuels, chemical building blocks, biobased polymers, 2G or microbial biosurfactants and CO_2 as a feedstock (Carbon Capture and Utilisation). The results are based on an extensive literature review, complemented by over 80 expert interviews and 13 stakeholder workshops organised across Europe in 2013 & 2014. This report presents the most significant barriers to the deployment of industrial biotechnology in Europe, and outlines 10 pragmatic recommendations by which they could be addressed: • Improve opportunities for feedstock producers within the bio-economy. • Investigate the scope for using novel biomass. • Develop a workforce which can maintain Europe's competitiveness in industrial biotechnology. • Introduce a long-term, stable and transparent policy and incentive framework to promote the bioeconomy. • Improve public perception and awareness of industrial biotechnology and biobased products. • Identify, leverage and build upon EU capabilities for pilot and demonstration facilities. • Promote the use of co-products from processing. • Improve the bioconversion and downstream processing steps. • Improve access to financing for large-scale biorefinery projects. • Develop stronger relationships between conventional and non-conventional players.	Final report of the FP7-funded project BIO-TIC[118]

[118] http://www.industrialbiotech-europe.eu/new/wp-content/uploads/2015/08/BIO-TIC-roadmap.pdf

19	Teagasc Technology Foresight: Technology tRansFoRming iRish agRi-Food and Bioeconomy	Various Authors, 2016	The Teagasc Technology Foresight 2035 focuses on the identification of emerging technologies that will drive the competitiveness and sustainable growth of the Irish agriculture and food industry and bio-economy sector over the next 20 years. Its goal is to identify new areas of technology in which Ireland needs to invest.	Ireland Initiative[119]
20	Renewable Chemical Biorefinery Commercialization, Progress, and Market Opportunities, 2016 and Beyond	Solegear Bioplastic Technologies Inc. and Biobased Technologies® LLC., 2016	This paper is a review of operating bio-refineries. It displays a range of technology solutions undergoing commercial development – beyond just advanced biofuels – to produce commodity and specialty renewable chemicals. Industrial biotechnology companies are pursuing renewable chemicals and bio-based materials because they can be commercialized at smaller scale, as well as promise environmental benefits, stable costs and novel properties in comparison to fossil fuel-derived chemicals. Competition to produce platform renewable chemicals provides manufacturers assurance of a steadily available, high-quality supply of renewable chemicals for consumer product applications.	Biotechnology Innovation Organization (BIO)

[119] https://www.teagasc.ie/media/website/publications/2016/Teagasc-Technology-Foresight-Report-2035.pdf

7.1 Key findings of the assessed studies

Biorefining is the sustainable synergetic processing of biomass into a spectrum of marketable food & feed ingredients, products (chemicals, materials) and energy (fuels, power, heat). It combines different steps of biomass utilization in an integrated system to conclude in a variety of bio-based products and to use biomass in an efficient way.

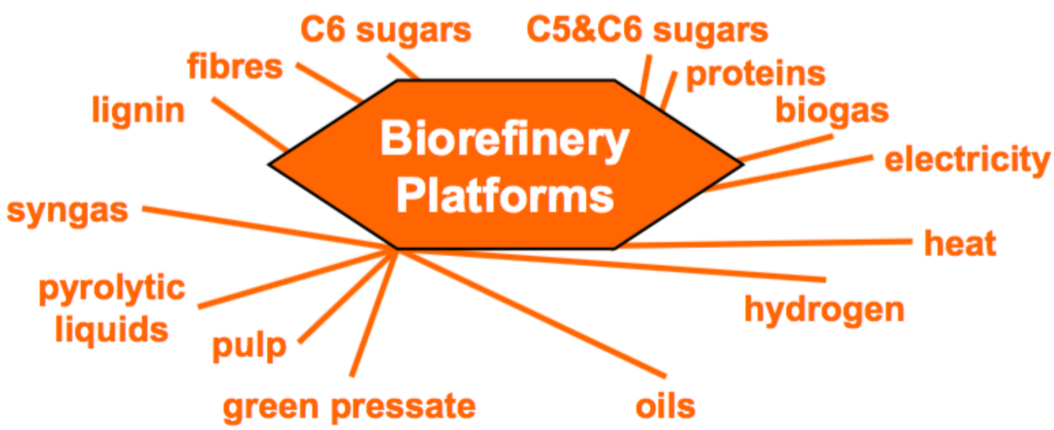


Figure 41: Examples for possible platforms in a biorefinery system
Source: IEA Bioenergy Task42

The Biobased Industries Consortium (BIC) defines biorefineries the following way:

> Biorefineries are processing facilities that convert biomass into food, food ingredients, feed, chemicals, materials, fuels and energy using a wide variety of conversion technologies in an integrated manner. A common goal for biorefineries is to use all parts of the biomass raw material as efficiently as possible, i.e. maximizing the economic added value, while minimizing the environmental footprint. In other words, a biorefinery aims to exploit all parts of the biomass by producing several products (typically a main product and several co-products), by cooperating actively with other companies to convert 'one's waste to another's raw material', and even by generating the energy, which powers the biorefinery itself. To date, many "types" of biorefineries have been developed. They rely on different technologies, but they all differ from (fossil) refineries in that biorefineries use renewable raw materials instead of fossil raw materials. The raw materials currently used in biorefineries show a great variety, as is illustrated in the diagram [Figure 42] below.
>
> Current biorefinery development set-ups follow two paths:
> - improvement and expansion of a conventional biomass processing facility;
> - implementation of a new processing concept converting biomass into value-added products.[120]

[120] Biobased Industries Consortium (BIC): Biorefineries (http://biconsortium.eu/sites/biconsortium.eu/files/downloads/BIC_fact_sheet_Biorefeneries_Sep2016.pdf)

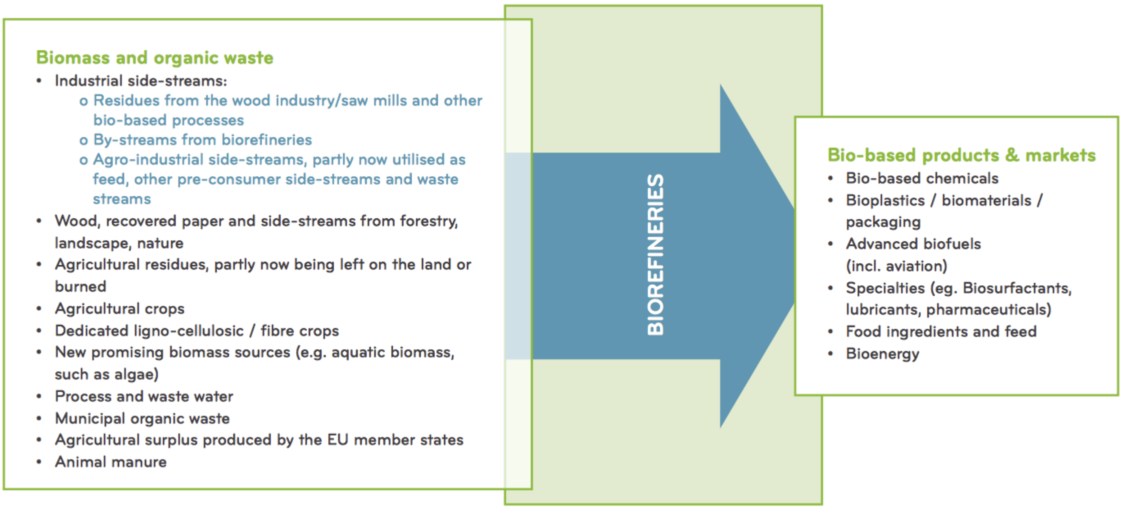


Figure 42: Bio-based value chains in biorefineries.
Source: SIRA 2013[121]

In general, biorefineries can be distinguished as energy-driven (or fuel-driven) and product driven biorefineries depending on the primary products derived from the system:

- In energy-driven (or biofuel-driven) biorefineries the main goal is to produce huge volumes of relatively low-value biofuel out of biomass.
- In product-driven (i.e. chemicals, materials) biorefineries, the main goal is to produce smaller amounts of relatively higher value-added bio-based products out of biomass.

Currently, only limited product-driven biorefineries are in operation, mainly because of the fact that some key technologies are still in the R&D, pilot and demo-phase – and because the European and national incentive frameworks only support the production of biofuels, especially second generation; but not the production of bio-based chemicals.

Depending on the concrete definition, experts count about 40 biorefineries in the European Union, mainly sugar, starch and oil-based, which have been running for decades. The webpage "Commercial Biorefineries in Europe[122]" gives a very good overview on biorefineries in Europe:

- Starch- and sugar-based biorefineries: 21
- Oil-based biorefineries: 6
- Lignocellulosic-based biorefineries: 4
- Pulp biorefineries: 1
- Grass-based biorefineries: 1
- Syngas-based biorefineries: 1

Together, this amounts to 34 biorefineries. In addition, 6 flagship biorefineries have been funded by BBI, so in total 40 biorefineries are in processing or under construction.

[121] SIRA: Bio-based and Renewable Industries for Development and Growth in Europa. 2013.
[122] https://biorrefineria.blogspot.de/p/listado-de-biorrefiern.html?m=1

New technology development can lead to improved efficiencies and additional products, especially in the chemical sector. The biggest lignocellulosic biorefinery in Europa is under construction in Finland: Metsä Group is building the world's first next-generation bioproduct mill in Äänekoski. One of the main products of the biorefinery will be cellulose fibres for textiles and biocomposites[123].

7.2 Trends and emerging markets

A higher resource efficiency in biomass utilization and saving greenhouse gas emissions have been the main drivers for all biorefinery technologies and different new plants that are currently at pilot, demonstration or commercial scale. The resources that are being considered are all kinds of biomass: first generation feedstocks such as sugar, starch and vegetable oil as well as second generation feedstocks such as lignocellulose, biowaste, algae, syngas and biogas.

Successful and mature technologies are mainly the ones that utilise sugar, vegetable oil and pulp. The lignocellulose based refineries that are based on fermentation are still at a demonstration scale and most of the current research is directed at these lignocellulose-based refineries. The biorefinery concepts such as biogas-based, or algal-lipid-based are still at a descriptive level or ready for proof of concept.

According to the studies, the degree of maturity of the biorefinery concepts, both between themselves and with respect to the different sub-concepts, is very heterogeneous.

[123] http://news.bio-based.eu/metsae-group-leads-the-finnish-bioeconomy/

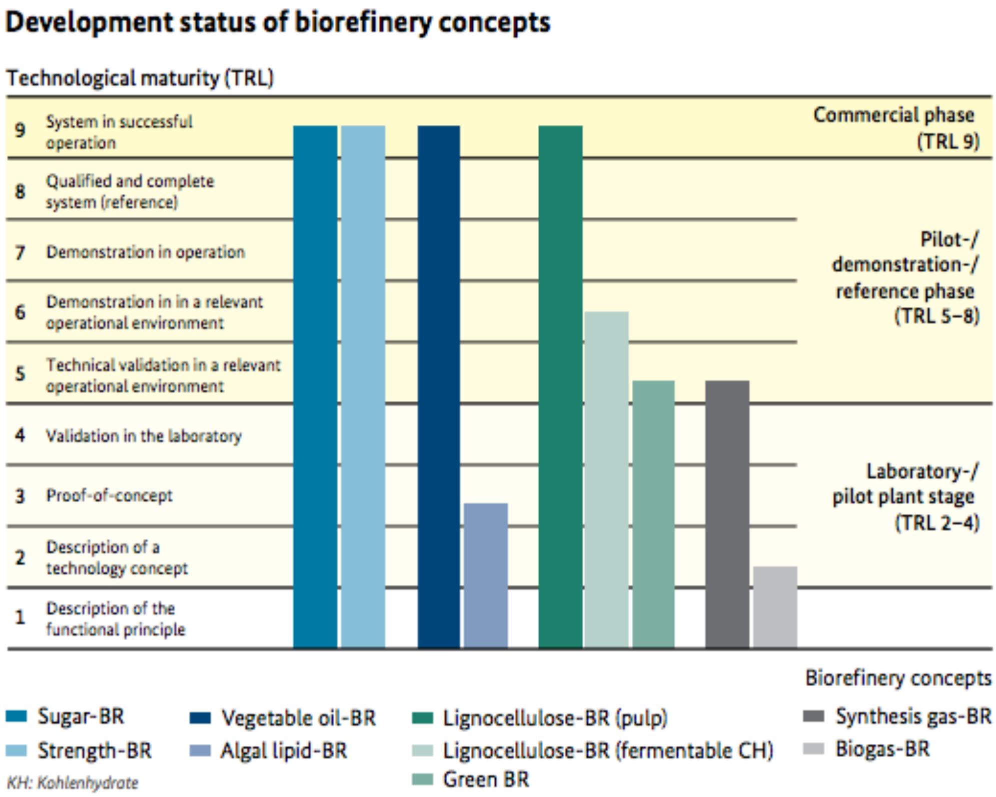


Figure 43: Development status of biorefinery concepts.
Source: Federal Government of Germany, 2012

The impact of biorefineries on climate change mitigation has also been an area of huge interest. Several studies which imply life cycle emission savings with a single product or multiple products in comparison to the petrochemical refinery have emerged. According to various papers, in the case of biorefineries sustainability assessment has been viewed as the important attribute for bio-based chemicals in a sustainable chemistry.

Another important aspect is still under discussion: Do we need huge biorefineries to be competitive or are also regional and decentralized concepts suitable?

Calculations show that lignocellulosic biorefineries using wood or lignocellulosic side streams need huge capacities of more than 500,000 t of biomass per year (e.g. Piotrowski et al. 2014), some sources even speak of 2 million t of biomass per year. Those dimensions lead to problems with feedstock supply and investment costs, only very few locations are suitable to accommodate such large volumes, for example huge harbours.

On the other hand, there are several concepts for small, regional biorefineries, that can often utilise special feedstocks such as grass, lupine or food-waste. Guaranteed and simple feedstock supply, lower investment and rural development are very promising aspects of such concepts. Efficiencies, robustness, costs and access to markets are still under research and development.

7.3 Discussion and identification of gaps

The only available study providing a comprehensive overview of the recent development status of biorefineries (Federal Government of Germany) was published in 2012, so a recent and European overview is missing. Several research papers and studies concentrate on specific molecules or describe the topic in a more general way and address overall topics of bio-based chemistry and biorefineries. Though there exists a gap in the resource utilization in the context of lignocellulose, there is also a lack of knowledge on technology and studies to provide competitive or at least similar products that are being produced in a conventional route.

There is a lack of studies or projects on the development of functionalities with chemicals produced in these biorefineries. For example, the research concentrates more on developing a value based processes and chemicals, but the market access is not well known and often cannot be funded in projects. The gap in research is prominent in the downstream towards industries such as personal care, healthcare or textiles.

Based on nova's expertise, we conclude that the strong focus on funding lignocellulosic biorefineries is questionable, since they can hardly be realized at small or medium scales and the technology is still a challenge. There are so many opportunities in the further development of sugar, starch and oil-based refineries to higher efficiencies and diversified chemical products as well as opportunities for specific crops and biomass flows in regional small biorefineries. Funding should be open to all kind of biorefineries.

8 Global trends

8.1 International markets

Table 29: Studies on international markets

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	Bio-based Products Minnesota's Opportunity and Challenge A Focus on BioPlastics	Agricultural utilization research institute 2012	While interest in bioplastics exists, awareness is lacking. To ultimately be successful, industry experts say there are issues within bioplastics that must be addressed, such as the financial equation. While manufacturers express a desire to use bio-based materials from both an environmental and marketing perspective, they have concerns about the ability of these materials to meet the specifications and standards of their customers. The paper proposes a process of education towards bio plastics and bio-based products, collaboration and support from the state, including a reduction or removal of barriers for a growth of bioplastics in Minnesota.	Link here[124]
2	The Emergent Industrial Bioeconomy	Golden, J. S. and Handfield, R., 2014	As presented, the market for bio-based products is growing in large part as a result of efforts by retailers, brands, manufacturers, consumers, and government officials to promote the environmental benefits and acceptance of these products as they become commercially viable. Some of the many bio-based products that are currently produced include bioplastics, biolubricants, biosolvents, and bio-surfactants. Other biosynthetics are gaining greater market share and consumer acceptance. In addition, many biofuel coproducts are emerging that can be produced from a variety of different sources of biomass.	

[124] http://www.auri.org/wp-content/assets/legacy/research/Biobased.Products.Report.pdf

3	The Bio-based Economy at a Crossroads: 15 Years of Progress and Next Steps	Erickson, B. 2015	The paper's vision is one in which largescale biorefineries are constructed to produce multiple products, not just fuels. But beyond that it sees synthetic biology driving a new wave of innovation and industrial biotech steadily increasing the number of applications in a myriad of manufacturing sectors. Future economic opportunities will be driven by consumer trends and the economies of scale for biorefining. Progress will not come without some challenges. But if the scientists, companies, and associations stay involved and constructively engaged with the public and policy makers, the future looks very bright.	
4	Bio-based Building Blocks and Polymers in the World Capacities, Production and Applications: Status Quo and Trends towards 2020 3rd Edition	Aeschelmann, F. et al. 2015	Bio-based polymers represent 2% of the total worldwide polymer capacity, in 2014, with a turnover of €11 billion. Bio-PET, for example, is mainly produced in Japan, Indonesia and India, and has seen a continuous growth capacity from 300,000 tonnes in 2011, to 600,000 tonnes in 2014, and an expected capacity of 7 million tonnes by 2020. However, bio PET remains about two times more expensive than petrochemical PET due to cheap crude oil. Price parity is expected, at the latest, by 2020. Just under 80% of all bio based polymers produced cover four market segments: Automotive and transport, Consumer goods, Building and construction, and Textiles, with a significant share dedicated to rigid packaging. The latter is expected to be the fastest growing sector, going from 13% in 2014 to 40% by 2020. With regards to regions, the study shows that Asia will see its market share in bio-based polymers grow from just over 50% in 2013, to over 75% in 2018. All other regions (Europe, North America and Australia) will see their market share drop by half to 2/3 of their 2013 values (17% to 7.5%; 18% to 4%; and .6% to .1%, respectively), while South America will see no change in the 2013 values (12%), by 2018.	This is a commercial study, a short version is available for free Link here[125]

[125] file:///Users/Luis/Downloads/15-12-03-Bio-based-Building-Blocks-and-Polymers-in-the-World-short-version.pdf

5	Bioeconomy Policy Synopsis and Analysis of Strategies in the G7	Bioökonomierat 2015	Germany, the USA and Japan have set themselves ambitious goals with specific national bioeconomy strategies. France, the UK, Italy and Canada are also providing much support to promote the development of the bio-based economy in practise. Within the G7 group, the European Union has become a driving force behind bioeconomy policy. Canada and the USA have developed utilization strategies focused on their natural assets. Key areas are the production of platform chemicals or bioenergy, such as wood pellets, bioethanol, and recently also next generation biofuels. In countries with few natural resources and a strong industrial structure, such as Germany, Japan, France and Italy, the bioeconomy is viewed much more from the point of view of its innovative potential and recently also its potential for industrial renaissance. Its focus is firstly on replacing fossil fuels, and the associated reduction in greenhouse gases, and secondly on achieving a technological advantage by means of new methods for processing biomass to make new products. Regional stakeholders also play a considerable role in the political promotion of the bio-based economy within some G7 countries. Together with the OECD, the EU is the only supranational stakeholder with a bioeconomy strategy. So far, neither the United Nations (e.g. UNEP, UNCTAD or FAO), nor the World Bank, nor the IPCC (Intergovernmental Panel on Climate Change), or the like have positioned themselves on the subject of the bioeconomy. Elements of bioeconomy, however, do play an important role in the World Bank initiated Green Growth Knowledge Platform.	Link here[126]
6	Advancing the Bio-based Economy: Renewable Chemical Biorefinery Commercialization, Progress, and Market Opportunities, 2016 and Beyond	Biotechnology Innovation Organization (BIO) 2016	Consumer product manufacturers have indicated that they are eager to use renewable chemicals in formulations in order to meet consumer demand for environmentally preferable products. The main challenge producers have cited for adoption of renewable chemicals is their ability to secure reliable, competitive supplies for large-scale product applications. Providing sufficiently large-scale supplies of drop-in renewable chemicals for some applications may require multiple manufacturers who adhere to common standards for chemical purity and quality. Some renewable chemicals – such as succinic acid and PLA – are already being produced commercially by multiple, competing companies and could potentially have commodity applications. A few additional renewable chemicals – such as butanol and isoprene – are approaching the same status. Several other renewable chemicals are being produced at commercial levels by a single company – such as 1,3-propanediol, propylene glycol and some diacids – with production tailored to niche product markets. Many additional companies are scaling up and	Link here[127]

[126] http://bioeconomia.agripa.org/download-doc/64046
[127] https://www.bio.org/sites/default/files/BIO_Advancing_the_Biobased_Economy_2016.pdf

			demonstrating new renewable chemical technologies. And in some cases, there are multiple companies competing to reach commercial scale. Forming partnerships with consumer product manufacturers or larger mid-market chemical producers – who can provide offtake agreements or capital investment in some form – is a common strategy for emerging companies commercializing new renewable chemicals. Ensuring that consumers receive the environmental, economic and performance benefits of renewable chemicals requires an integrated effort across this entire production value chain.	
7	European Bioeconomy in Figures	Piotrowski, S. et al. 2016	The bioeconomy comprises those parts of the economy that use renewable biological resources from land and sea – such as crops, forests, fish, animals and micro-organisms – to produce food, materials and energy. A new study now shows which macroeconomic effects are generated by these activities, e.g. turnover, employment etc. The data, generated by nova-Institute on behalf of the Bio-based Industries Consortium (BIC) will be updated annually. The analysis of the Eurostat data of 2013 shows that the turnover of the total bioeconomy, including food and beverages and the primary sectors agriculture and forestry, results in 2.1 trillion EUR in the EU-28. Roughly half of the turnover is accounted for by the food and beverages sector, almost a quarter is created by the primary sectors, agriculture and forestry. The other quarter is created by the so-called bio-based industries, such as chemicals and plastics, pharmaceuticals, paper and paper products, forest-based industries, textile sector, biofuels and bioenergy. The bioeconomy employs 18.3 million people in total. The primary biomass production, mainly agriculture plus forestry and fishery, generates a lot of employment (58%) but low turnover (21%). The data show clear differences between groups of Member States: e.g. the Eastern European countries Poland, Romania and Bulgaria apparently are stronger in less value added sectors of the bio-based economy that generate a lot of employment. In comparison, Western and Northern European countries generate much higher turnover compared to the employment generated. The countries with the highest ratio between turnover and employment are Ireland, Finland and Belgium.	Link here[128]
8	An Economic Impact Analysis of the U.S. Bio-based Products Industry	United States Department of Agriculture 2016	The paper in an update of the 2015 version and found there has been a fast increase in the employment and value of the Bio economy in the US. As a consequence, it has displaced a considerable quantity of petroleum, along with other environmental benefits. A wide range of both near-term and longer-term opportunities exist that the public and	Link here[129]

[128] http://bio-based.eu/?did=42475&vp_edd_act=show_download
[129] https://www.biopreferred.gov/BPResources/files/EconomicReport_6_12_2015.pdf

			private sectors can undertake to advance the bio-based products industry. Those opportunities include creating a bio-based products industry consortium and production credits, increasing the visibility of the BioPreferred program's "USDA Certified Bio-based Product" label, and expansion of other related USDA programs.	
9	Asian markets for bio-based chemical building blocks and polymers	Baltus, W., Wobalt Expedition Consultancy, 2017	The nova trend report "Asian markets for bio-based chemical building blocks and polymers" shows latest data and development in China, Japan, Malaysia, South Korea, Taiwan and Thailand. A global capacity of 2.4 million tonnes bio-based polymers was established in 2016, from which more than 45% of the most important bio-based polymers are produced in Asia. The worldwide capacity is expected to reach 3.6 million tonnes in 2021, nearly 52% of this volume will be installed in Asia. This equals an increase of installed capacities of 71% in the next five years. For bio-based building blocks, the report sees an increase of the implementation of biorefineries and bio-hubs in South-East Asian countries to strengthen their competitiveness. Stronger emphasis on cooperation and partnership along the value chain and with R&D providers becomes a key factor to success. Potential investors and customers in Asia are eager for a change in governmental policies and incentives. At the moment, government measures are mostly targeted at enhancing the export capabilities of countries and generating technology transfers. Countries such as Thailand have reacted to the demands of the market and introduced "roadmaps" to support the introduction of bio-based plastics or/and biotechnology. Main increase of future production capacities (and shares) is expected for PLA and polyamides (PA). PHAs are another biopolymer group in focus of Asia, capacity volumes and underlying trends are another focus of the nova trend report. The drop-in bio-based polymer PET, which is only partly bio-based at present, holds the major share of the total Asian production capacity. In 2021, PET is expected to contribute with 59% to the total capacity of biopolymers in Asia, which are in focus of this trend report. "Biodegradable, compostable" polymers (such as PLA, PBS, PBAT, PHAs) are expected to be contributing about 25% to the Asian production of bio-based polymers in 2021. However, that means that about 75% of the total bio-based production in Asia will be focusing on durable polymers.	This is a commercial study, a short version is available for free Link here[130]
10	Bio-based Building Blocks and Polymers Global Capacities and	Aeschelmann et al., 2017	Update from the report 2015 (source 4), fourth edition. Comprehensive overview on the development of bio-based polymers and building-block for bio-based polymers world wide, production capacities and trends. More details below in the text.	This is a commercial study,

[130] file:///Users/Luis/Downloads/17-01-SHORT-VERSION-Asian-bio-based-polymer-markets (1).pdf

	Trends 2016–2021			a short version is available for free[131]

[131] http://bio-based.eu/media/edd/2017/03/17-02-Bio-based-Building-Blocks-and-Polymers-short-version.pdf

8.1.1 Key findings of the assessed studies

The most recent market study on bio-based came to the conclusion that these materials show growth rates at the "same level as global polymers: Worldwide production capacity is forecasted to increase from 6.6 million tonnes in 2016 to 8.5 million tonnes in 2021. In contrast to a 10% annual growth between 2012 and 2014, the capacity growth data now show a 4% annual growth rate from 2015 to 2021 – which is almost the same as for the overall global polymer capacity. The main reasons for this slow increase in capacity are low oil prices, low political support and a slower than expected growth of the capacity utilization rate. … The bio-based polymer turnover is about € 13 billion worldwide in 2016 compared to € 11 billion in 2014. … The bio-based share of overall polymer capacity had grown over the years: it was 1.4% in 2011. In recent years, the bio-based share has been stagnating at approximately 2%. The bio-based polymer annual capacity growth rate is currently similar to the global polymer annual capacity growth rate of 3–4%." **(**Aeschelmann et al. 2017).

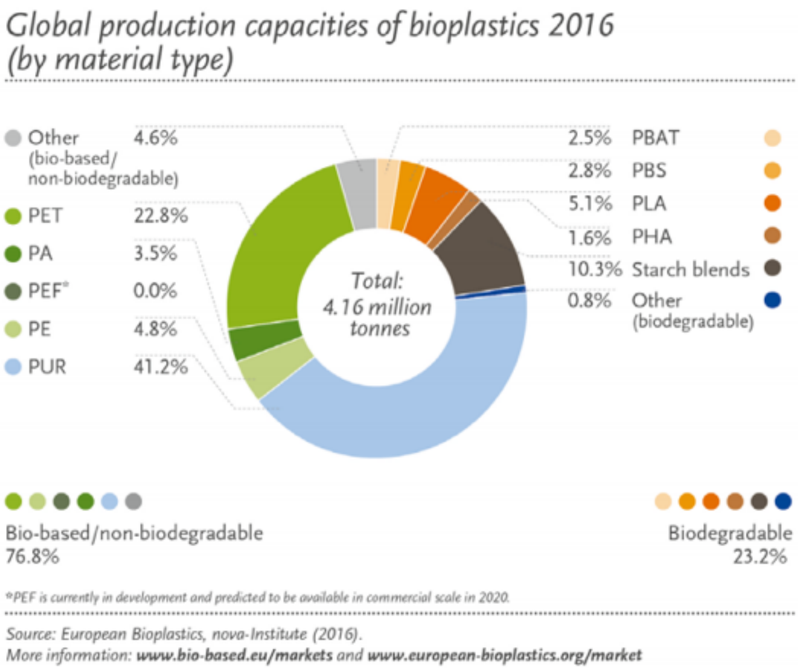


Figure 44: Global production capacities of bioplastics 2016 by material type

(the data differ from the 6.6 million tonnes in the quotation above because of another biopolymer selection; in the figure Cellulose acetate and Epoxy resins are not included). Source: Aeschelmann et al. 2017

While interest in bioplastics exists, awareness continues to be lacking (Agricultural Utilization Research Institute 2012). Currently, the world market for bio-based products is growing in large part as a result of efforts by retailers, brands, manufacturers, consumers, and government officials to promote the environmental benefits and acceptance of these products as they become commercially viable (Golden 2014). Some renewable chemicals – such as succinic acid and PLA – are already being produced commercially by multiple, competing companies and could potentially have commodity applications. A few additional renewable chemicals - such as butanol and isoprene - are approaching the same status. Several other renewable chemicals are being produced at commercial levels by a single company with production tailored to niche product markets - such as 1,3-propanediol, propylene glycol and some diacids (BIO 2016).

During the last years, there has been a positive development for different new bio-based building blocks, which are the precursor for biopolymers, but also for a lot of additional applications such as surfactants, lubricants, paints, coatings and many more: "The total production capacity of the bio-based building blocks reviewed in this study is 2.4 million tonnes in 2016 and is expected to reach 3.5 million tonnes in 2021, which means a CAGR of 8%. The bio-based building block annual capacity growth rate is twice as high as the bio-based polymer annual capacity growth rate. The most dynamic developments are spearheaded by succinic acid and 1,4-BDO, with MEG as a distant runner-up. Bio-based MEG, L-lactic acid (L-LA), ethylene and epichlorohydrin are relatively well established on the market." (Aeschelmann et al. 2017)

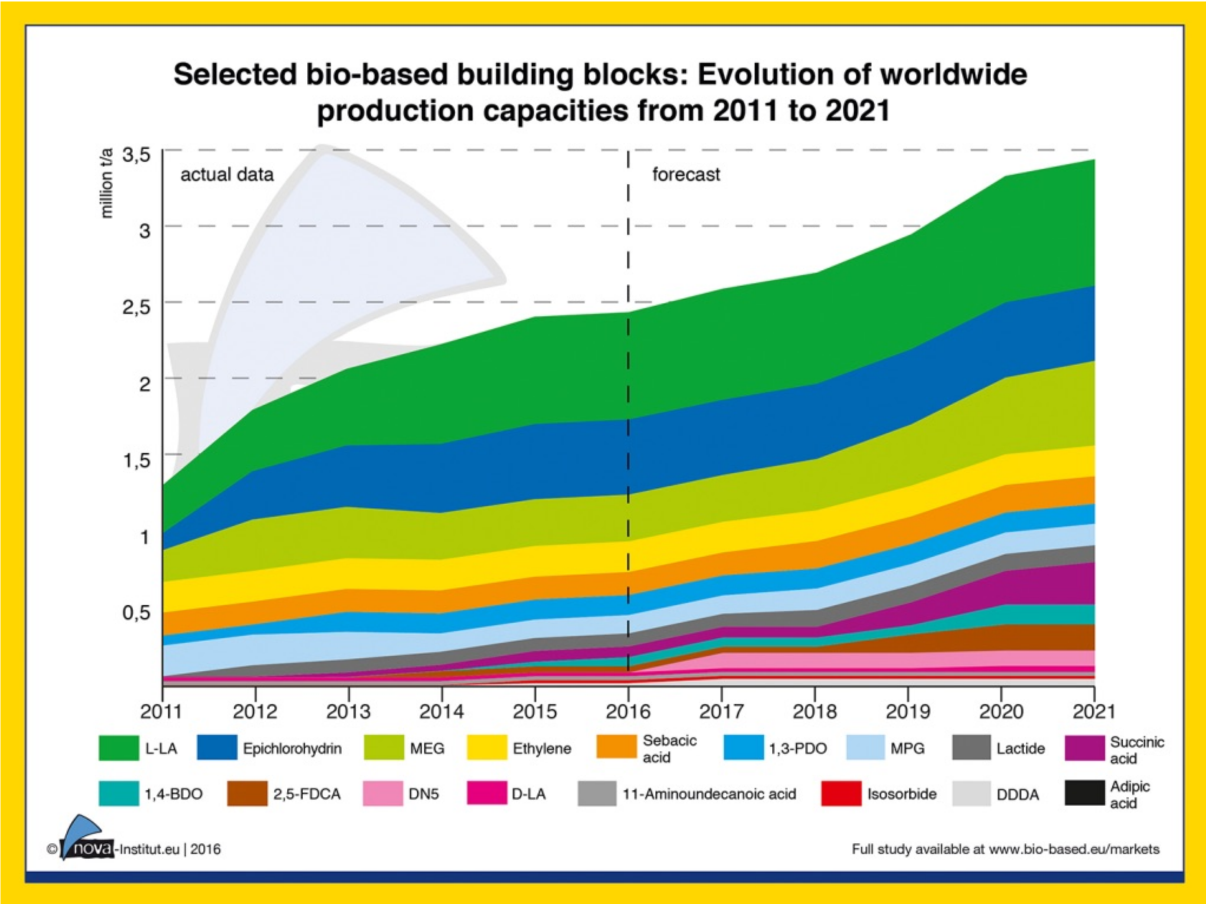


Figure 45: Selected bio-based building blocks: Evolution of worldwide production capacities from 2011 to 2021
(Aeschelmann et al. 2017)

With regards to regions, most investment in new bio-based polymer capacities will take place in Asia because of better access to feedstock and a favourable political framework. Europe's share and North America's share are projected to remain almost stable, from 27.1% to 26.0%, and from 23.4% to 22.5% respectively, whereas Asia's is predicted to increase from 43.4% to 46.9%. South America is set to fall from 5.9% to 4.4%. In other words, world market shares are expected to remain relatively stable. All regions are predicted to experience developments in the field of bio-based building block and polymer production. (Aeschelmann et al. 2017).

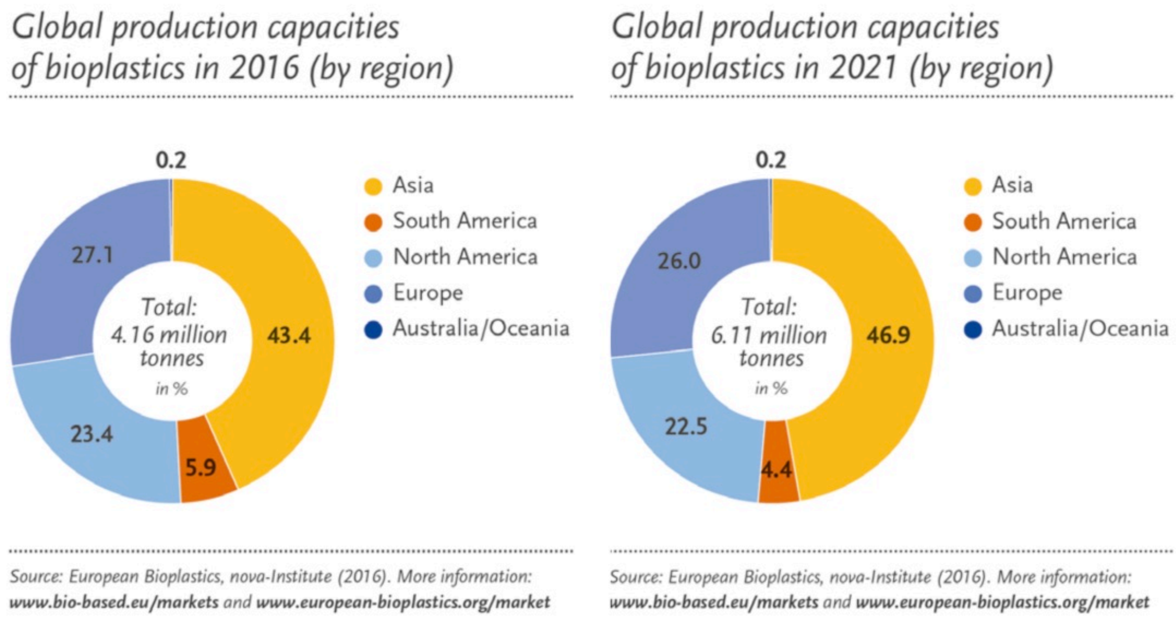


Figure 46: Evolution of bio-based production capacities by regions

Source: Aeschelmann et al. 2017

Within the G7 group, the European Union has become a driving force behind bioeconomy policy. Canada and the USA have developed utilization strategies focused on their natural assets (Bioökonomierat 2015). This has led to a fast increase in the employment and value of the bioeconomy in the US. As a consequence, it has displaced a considerable quantity of petroleum. The displacement is twofold: there is a direct replacement of chemical feedstocks that have traditionally been derived from crude oil refineries with chemical feedstocks now being derived from biorefineries, at a current estimate of 150 million gallons per year; secondly, indirect replacement as through the increased use of natural bio-based materials as substitutes for synthetic (petroleum-based) materials, such as the use of natural fibres in packaging and insulation materials, at a current estimate of 6.8 million gallons per year. This is equivalent to taking 200,000 cars off the road, a year (United States Department of Agriculture 2016). The same report also states that up to 1.53 million direct jobs have been created in the US in the bio-based sector, in the year 2014, and supported 4.22 million total jobs throughout the economy in the United States (United States Department of Agriculture 2016). The total value added contribution to the U.S. economy from biobased products was $393 billion in 2014, the most recent year for which data are available (United States Department of Agriculture 2016).In countries with few natural resources and a strong industrial structure, the bioeconomy is viewed much more from the point of view of its innovative potential and recently also its potential for industrial renaissance (Bioökonomierat 2015). Its focus is firstly on replacing fossil fuels, and the associated reduction in greenhouse gases, and secondly on achieving a technological advantage by means of new methods for processing biomass to make new products (Bioökonomierat 2015).

Together with the OECD, the EU is the only supranational stakeholder with a bioeconomy strategy. So far, neither the United Nations (e.g. UNEP, UNCTAD or FAO), nor the World Bank, nor the IPCC (Intergovernmental Panel on Climate Change), or the like have positioned themselves on the subject of the bioeconomy (Bioökonomierat 2015).

The main challenge producers have cited for adoption of bio-based products is their ability to secure reliable, competitive supplies of feedstock for large-scale product applications. Such a supply may require multiple manufacturers to adhere to common standards for chemical purity and quality (BIO 2016). While manufacturers express a desire to use bio-based materials from both an

environmental and marketing perspective, they have concerns about the ability of these materials to meet the specifications and standards of their customers (Agricultural Utilization Research Institute 2012).

Proposals for a more sustainable global bio-based product market include one in which large-scale biorefineries are constructed to produce multiple products, not just fuels (Erickson 2015). With Metsä fibre in Finland, the biggest European biorefinery mainly for bio-based products, such as cellulose textile fibres and bio-based chemicals, is under construction and ready for production in the year 2018.

Furthermore, some papers reviewed propose a process of education towards bioplastics and bio-based products, collaboration and support from the state, including a reduction or removal of barriers for a growth of bioplastics (Agricultural Utilization Research Institute 2012). Forming partnerships with consumer product manufacturers or larger mid-market producers – who can provide offtake agreements or capital investment in some form – can be a common strategy for emerging companies commercializing new bio-based products (BIO 2016).

8.1.2 Discussion and identification of gaps

The production capacity of bio-based polymers is growing worldwide, but since 2015 only with the same speed as the total polymer market. So there is a constant share of about 2% of biopolymers in the total polymer market and no further replacement of petrochemical polymers foreseen as of now. The main reasons are low oil prices, low political support and a slower than expected growth of the capacity utilization rate.

Most investment is going to the core of the bioeconomy: bio-based building blocks and platform chemicals. The capacities show about 8% yearly growth. Based on this, new building blocks, new bio-based polymers, coatings, surfactants and others will follow. World market shares are expected to remain relatively stable, with Europe and the US staying on the same level, while Asia wins a little and South America loses a little.

Data on these developments are rare. Only commercial reports of very different quality are available for the production capacities of bio-based building blocks and biopolymers. Regarding other bio-based materials, the data situation is even worse. Some of the commercial reports have free available summaries. Data on the production are not available. So only some international experts can estimate production and trends.

8.2 Policies and initiatives outside the EU

Table 30: Studies relevant to worldwide bioeconomy policies

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	Industrial material use of biomass Basic data for Germany, Europe and the world	Raschka, A. and Carus, M. 2012	The document provides an overview of the available basic data for material use in Germany, Europe and worldwide. Material use slightly outweighs energy use worldwide.	Link here[132]
2	Biomass Industrialization Strategy	Ministry of Agriculture, Forestry and Fisheries 2012	Japan's biomass strategy started with biomass utilization promotion in 2002, and the Basic Act was established in 2009. After the Great East Japan Earthquake and subsequent nuclear accident happened, the biomass industrialization strategy was drawn as principle to create regional green industry and fortify an independent and distributed energy supply system. The Act sets up a council comprised of related government bodies (seven ministries in Japan) to promote comprehensive, uniform, and effective biomass utilization. The National Plan for the Promotion of Biomass Utilization sets up three numerical targets for biomass utilization by the year 2020. National target of average utilization ratio is set for each type of biomass to promote high utilization biomass based on their types and to clarify the necessary measures to be taken on the national level. Creation of the Biomass Industrial Community is presented to realize the Biomass Industrialization strategy. Establishment of green industry utilizing regional biomass and recycling-based energy system in combination with solar and small-scale hydro-electric power generation. Creation of environmental-friendly and disaster-resistant communities (Biomass Industrial Communities), centering on the biomass industry. Furthermore, attention is given to Biomass Town Advisors, human resources supporting the formulation of the Biomass Town Plan and supporting consideration of biomass industrialization in order to promote biomass utilization.	Link here[133]

[132] http://www.nova-institut.de/download/Industrial_Material_Use_of_Biomass_nova
[133] http://www.maff.go.jp/e/pdf/reference6-8.pdf

	A Policy Template to Support the Emergence of the Bioeconomy	Erickson, B., 2012	The document proposes the following policy advice in order to promote the emergence of the bioeconomy. Establish a matching grant program to fund projects to construct new bio-refineries, or to repurpose or retrofit existing idle or underutilized manufacturing facilities for the production of advanced biofuels and/or renewable chemicals. Create programs to streamline and expedite the permitting process for biorefinery construction. Direct state Departments of Agriculture to conduct and finalize research on the feasibility of providing state crop insurance to producers of corn stover, straw, and woody biomass, as well as energy cane, switchgrass, and camelina, and utilize that research to work with stakeholders, including industry and policymakers, to establish formal state crop insurance programs that will cover PGECs. Require state agencies to give purchasing preference to bio-based products during procurement cycles (i.e., require agencies to use all bio-based alternatives when available and cost-competitive). Require state agency procurement and usage of advanced biofuels (i.e., require all government fleet vehicles be flexfuel capable and require use of renewable fuels in government vehicles capable of their use). Provide an investment tax credit (ITC) for new next generation biorefineries to help defray capital costs for construction or retrofit of existing facilities. Establish production tax credit incentives for advanced biofuels, renewable chemicals, and bio-based products. Create campaigns to educate the public on the availability and societal benefits of industrial biotechnologies. Develop state-based educational programs and curricula to facilitate workforce training in the industrial biotech sector at community colleges and universities. Create clusters and incubators that will focus on fostering new industrial biotech companies and tech transfer.	Link here[134]
4	Strategies and Policies for the Bioeconomy and Bio-Based Economy: An Analysis of Official National Approaches	Staffas, L. Gustavsson, M. and McCormick, K. 2013	The aim of this study is to analyze selected national strategies and policies regarding the development of a bioeconomy and to clarify similarities and differences between them. A comparative overview of the strategies and policies for developing a bioeconomy in the EU, USA, Canada, Sweden, Finland, Germany and Australia. Conclusions show that the main emphasis is often to enhance the economy of a nation and provide new employment and business possibilities, whereas the aspects of sustainability and resource availability are addressed only to a limited extent in many of the documents.	Overarching with EU policy, national policy, global trends. Climate change mitigation Link here[135]
5	BIOECONOMY An Agenda for Brazil	Harvard Business Review analytic services,	The document is in line with the 2013-2022 Strategic Road-Map for the Industry. According to the Ministry of Environment (MMA) and the Ministry of Agriculture, Livestock and Food Supply (MAPA), Brazil ranks first in biodiversity on the planet, with	Link here[136]

[134] http://www.mdpi.com/2071-1050/5/6/2751/pdf-vor
[135] http://www.mdpi.com/2071-1050/5/6/2751/pdf-vor
[136] http://arquivos.portaldaindustria.com.br/app/conteudo_24/2013/10/18/411/20131018135824537392u.pdf

		2013	more than 20% of the world's living species in its territory. This scenario shows Brazil's potential to become a world power if it manages to overcome the barriers. Knowledge and interest of all social sectors, (private companies, government and civil society) regarding the risks resulting from the lack of investments in the development of policies and updated practices for use of resources originated from biodiversity and the development of products and services placed on the top of the value chain, is extremely important. The factor investment in research and development, and investments to stimulate innovation in high value added sectors such as biomedicine, energy and alternative fuels, biotechnology applied to food production, among others, appears as a priority, too. Investment in physical infrastructure and human resources, together with tax incentives for a high value added production are part of the public policies that must be given priority by the government. Despite the adverse feeling indicated, it is possible to notice the advances made towards the development of a more favourable environment regarding the bioeconomy and its evolution in Brazil.	
6	National Biomass Strategy 2020: New wealth creation for Malaysia's biomass industry	Agensi Inovasi Malaysia (AIM), 2013	Malaysia currently generates about 12 percent of GNI from the agriculture sector. Within agriculture, by far the largest contributor to GNI is the palm oil sector, contributing about 8 percent. The palm oil sector correspondingly generates the largest amount of biomass. The vast majority of the oil palm biomass being generated today is returned to the field to release its nutrients and replenish the soil. However, there is also the potential to utilise this biomass for a variety of additional high value end-uses, including but not limited to the production of wood products, pellets, bioenergy, bioethanol and bio-based chemicals. Not surprisingly, the highest-value opportunities – bioethanol and bio-based chemicals – also carry the highest technological uncertainties and competitive risks. Biomass should not be removed from the field without consideration of its nutrient value and protection to the top soil. However, there is the potential to retain in the field the portion of the biomass that has the highest nutrient value but the lowest downstream value, as represented by its carbohydrate content, and replace the balance with inorganic substitutes. Should higher value bio-based chemicals materialise earlier or should Malaysia capture a bigger share of the global bio-based chemicals market, biomass can be diverted from energy (such as pellets) to capture these higher	Link here[137]

[137] https://biobs.jrc.ec.europa.eu/sites/default/files/generated/files/policy/Biomass Strategy 2013.pdf

			value opportunities. The development of partnerships is critical for mobilising the biomass, and the government has already put in place certain incentives and strategies to encourage development as a result of this National Biomass Strategy.	
7	Policies for Bioplastics in the Context of a Bio-economy	OECD 2013	In the current and foreseeable future, bioplastics are likely to comprise a mix of both biodegradable/compostable bioplastics and durable bioplastics. The attractiveness of bioplastics as replacements for petro-based plastics is dependent in part on their ability to meet environmental as well as economic goals. These are their sustainability, from production to end of life, along with job creation Despite these potential benefits, there are also many actual and potential barriers to the growth of a bioplastics sector. These include difficulty in assuring a constant stream of biomass, lack of regulatory frameworks and critical mass for recycling, among others. Many policies and policy instruments have the potential to affect the development of the bioplastics sector. These include agricultural policies, R&D support policies and trade and industry policies, and mechanisms such as subsidies and tax incentives, quota systems, standardisation schemes and regulatory measures.	Link here
8	Alternative Fuels: A state policy analysis	Skinner, A.; Rego, J. 2014	This research examines correlations between current policy and AFVs. In addition, this research provides a valuable look at which states have certain types of policies, and how these policies might relate to the number of AFVs and alternative fueling infrastructure in each state. There are three important distinctions that impact AFV policy: the origination of the policy (whether it is a state, local, or utility policy), the target of the policy (who is affected by the policy), and the type of policy mechanism (e.g., financial incentive, or a fee/tax policy). This research suggests that states with more laws and incentives that originate at the local or utility level are more likely to have a higher number of AFVs per capita. The type of policy mechanisms with the strongest relationship to AFVs per capita are: Grant or rebate policies for the purchase of AFVs, regardless of targeted market segment, had some of the strongest correlations with the number of AFVs per state. One example would be a policy that provides grants to purchase alternative fuels. Discount policies geared toward fuel use had a relatively strong correlation to the number of AFVs per state. One example would be an electric utility rate discount for electric vehicle (EV) charging. Policies allowing an exception, such as a tax exemption, had some of the strongest correlation observed. One example would be a policy that exempt alternative fuels from certain kinds of taxation.	

9	WHY BIO-BASED? Opportunities in the Emerging Bioeconomy	Golden, J and Handfield, R. B. 2014	While there is wealth of data and information regarding the economic impact of the bioeconomy in Europe and various nations, there is a lack of understanding and quantification of the economic benefits of the bioeconomy and specifically the non-fuel bioeconomy in the U.S. There are challenges facing the continued expansion of the bioeconomy. These include reliable availability of raw materials with increased climate and severe weather impacts, water availability, and stability of the markets. In the U.S., the United States Department of Agriculture (USDA) BioPreferred program and Federally-supported research continue to drive investment in research and development (R&D) and make available broader sets of bio-based consumer products. Across the globe, nations are investing in Public/Private Partnerships to expand their bio-based economy for domestic and international consumers. Continued investments are needed to establish a bio-based infrastructure while ensuring that the economics of bio-based feedstocks are competitive with existing, petroleum-based feedstocks.	Link here[138]
10	South Africa launches its Bioeconomy Strategy	Department of Science and Technology, Republic of South Africa 2014	Government's newly launched Bioeconomy Strategy provides a vision to guide biosciences policy as well as research, development and innovation (RDI) investments, with the aim of the bioeconomy contributing 5% to South Africa's GDP by 2050. It represents a shift from developing the biotechnology sector to developing a bioeconomy, which is cross-disciplinary, and promotes holistic solutions and world-class innovation. "Bioeconomy" refers to activities that make use of bioinnovations, based on biological sources, materials and processes to generate sustainable economic, social and environmental development. In order to ensure that the wealth of indigenous knowledge is used for the benefit of the people of South Africa, the nation will link bio-industry sectors with cross-cutting indigenous knowledge-based technology innovation programmes. This inclusive innovation and holistic model will form strong linkages with the three sectors of the Bioeconomy Strategy, namely Agriculture, Industrial and Environmental Bio-innovation, and Health. Agriculture: The focus for agriculture is to strengthen innovation to ensure food security, enhance nutrition, and enable job creation. Industry: The focus for industry and the environment is to prioritise RDI in biological processes for the production of goods and services, while enhancing water and waste-management practices in support of a green economy	

[138] https://www.biopreferred.gov/files/WhyBiobased.pdf

			Health: The focus for health is to support and strengthen the country's local RDI capabilities to manufacture active pharmaceutical ingredients (APIs), vaccines, biopharmaceuticals, diagnostics and medical devices to address the disease burden while ensuring security of supplies of essential therapeutics and prophylactics	
11	An innovative perspective: Transition towards a bio-based economy	van Beeck, N. Moerkerken, A., Kwant, K. & Stuij, B. 2014	The development of energy systems on the one hand, and the development of the agricultural sectors on the other are mutually dependent. Humanity consumes vast amounts of carbon each year in the form of food, feed, materials or energy. Most of this carbon is fossil carbon, and most of this fossil carbon is used for energy. Obviously, a considerable amount of bio-based carbon is associated with agricultural production. Evidence is accumulating to indicate that, with current production patterns, we are exceeding the planetary boundaries in such a way that humanity is threatened. Cascading is a precondition in the transition towards a bio-based economy, as part of the concept of the 'Trias Biologica', which is a logical concept to feed both people and livestock, to produce enough materials and energy to meet demand, *and* at the same time stay well within the planetary boundaries. Trias Biologica. First of all, a *de-carbonization* of the economy is necessary. Secondly, fossil carbon need to be substituted with sustainably produced bio-based carbon. And thirdly, cascading of the biomass is required. De-carbonizing is mainly targeted at the energy system. This *substitution* is the second component of the Trias Biologica. It is essential that this bio-based carbon is produced and consumed in a sustainable manner, in order to stay well within the planetary boundaries. C*ascading*, an essential element in sustainable agriculture, in order to optimize the use of bio-based resources with bio-refinery and circular process chains. This approach involves bio-refinery to extract minerals and other useful products in waste streams, making optimum use of every next step in the refinery process. Cascading also implies production chains being made more circular, by reusing minerals at the place of extraction as much as possible to avoid local depletion or eutrophication of the soil.	
12	Bio-based Chemicals and Bioplastics: Finding the Right Policy Balance	OECD 2014	This report examines the reasons why governments may wish to look at their policy balance and consider treating bio-based materials production similarly to fuels and electricity applications. Policy options to support bio-based materials have been broadly divided into two categories in this report: 1. Balancing policies for fuels, electricity and bio-based chemicals and reducing the competition for biomass; 2. Addressing policy gaps throughout the value chain.	Link here[139]

[139] http://www.biobasedeconomy.nl/wp-content/uploads/2014/09/OECD-2014_Biobased-Chemicals-and-Bioplastics.pdf

			A holistic approach to policy is more likely to lead to a successful bioeconomy, with governments avoiding creating policies in one area that may create policy problems elsewhere. One option is to apply the policy support measures that are currently available to biofuels and bioelectricity to bio-based materials. The major policies that are most likely to stimulate investment in bio-based materials are quotas/mandates and tax incentives. Public procurement acts as a demand-side measure to stimulate market uptake. Another, potentially very effective, measure would be a planned phasing out of fossil fuel consumption subsidies. Current priorities include: allowing bio-based materials to compete for biomass on price with bioelectricity and biofuels; rectifying the market distortions caused by fossil fuel subsidies; heading off future competition for crude oil demand; and correcting for any excessive regulatory impacts. If governments wish to realise a successful bioeconomy in the future, the case for supporting the production of bio-based chemicals and plastics warrants serious attention.	
13	National Biotechnology Development Strategy 2015-2020	Department of Biotechnology Ministry of Science & Technology Government of India 2015	National Biotechnology Development Strategy I provided the impetus for and helped in building indigenous capabilities in health, food and environment. The new strategy would seamlessly build on the earlier strategy to accelerate the pace of growth of biotechnology sector at par with global requirements. This strategy seeks to address a number of identified challenges in terms of tailor-made human capital for scientific research and entrepreneurship; research priorities, resources, and core facilities; creation of investment capital; intellectual property regime; technology transfer, absorption, diffusion and commercialization; regulation standards and accreditation; biotechnology partnerships between public and private sectors both nationally and globally and public understanding of biotechnology. Important focus is given to inclusive development by nurturing entrepreneurship aiming at protecting and promoting intellectual property, technology transfer, and SME support systems.	Link here[140]
14	The Oceans Economy: Opportunities and Challenges for Small Island Developing States	UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT (UNCTAD)	The concept of the oceans economy, also referred to as the blue economy, is one that simultaneously promotes economic growth, environmental sustainability, social inclusion and the strengthening of oceans ecosystems. The oceans economy can contribute to addressing some of the concerns associated with economic and environmental vulnerability, including those associated with remoteness, by fostering international and regional cooperation under an 'ocean space approach', which is also expressed in the literature as marine spatial planning. Well-managed sectoral reforms, parallel regulation and institution building in	Link here[141]

[140] http://www.dbtindia.nic.in/wp-content/uploads/DBT_Book-_29-december_2015.pdf
[141] http://unctad.org/en/PublicationsLibrary/ditcted2014d5_en.pdf

		2015	key environmental services sectors, such as wastewater treatment and remediation services, can support further investment in sectors that promote sustainable oceans in Small Island Developing States (SIDS). SIDS can also consider approaches to advance the design and implementation of regional regulatory and institutional frameworks for access and benefit-sharing for marine bio-prospecting in order to harness any potential benefits that result from research and development activities. Bio-prospecting of marine genetic resources offers interesting opportunities for benefit-sharing and creation of scientific capacities in SIDS, especially in relation to pharmaceuticals, cosmetics and food products development.	
15	Balancing the bioeconomy: supporting biofuels and bio-based materials in public policy	Philp, J. 2015	In the vast majority of countries that have bioenergy and biofuels policies, there is either no policy support for bio-based materials (especially chemicals and plastics) or it is limited to R&D subsidy. And yet, studies repeatedly show that higher added value and job creation are to be found in materials production. In general, policies for innovation and deployment need to encourage experimentation to develop new options that can help strengthen environmental performance at the lowest cost. However, with time, process improvements should result from these policies, and it would be prudent then to phase them out to prevent market distortion. It specifically addresses high-volume, low value chemicals because these have the greatest impact in replacing the oil barrel and in emissions reduction. These are precisely the chemicals that are unattractive to the young bio-based industry as it is extremely difficult to synthesise them efficiently at scale in competition with the petrochemicals industry. Such a mechanism should retain ultimate flexibility to reflect changing circumstances e.g. as mandated production targets are met, it should be possible for indirect instruments such as tax credit schemes to take over as the former are phased out. Ultimately, as market competitiveness is achieved, all forms of public support would be removed.	
16	Making Bioeconomy Work for Sustainable Development	Communiqué Global Bioeconomy Summit 2015	Bioeconomy policy should not be fragmented into diverse policy areas or technology sectors, but comprise RD&I, agriculture/ forestry/marine sectors, food, healthcare, biotechnology, converging technologies, renewable energy and conservation, and all these in combination with digitalization. For bioeconomy to become a key driving force of sustainability transformation in the circular economy, a more systematic, inter-sectoral and international approach is needed. Three key areas of action have been agreed upon that are crucial for the creation of a sustainable bioeconomy: (1) promoting innovative as well as proven technologies and measures for a sustainable bioeconomy, (2) establishing good governance for	Link here[142]

[142] http://gbs2015.com/fileadmin/gbs2015/Downloads/Communique_final.pdf

			a sustainable bioeconomy, (3) initiating and strengthening international dialogue and cooperation.	
17	FEDERAL ACTIVITIES REPORT ON THE BIOECONOMY	The Biomass Research and Development (R&D) Board 2016	While the United States is a global leader in promoting the use of sustainably produced feedstocks to fuel economic activity and growth, the bioeconomy is still in its early stages. A transition is needed from a fossil-based economy to an economy that is fueled by sustainable and renewable energy, of which biomass plays a critical role. Assisted by public-private partnerships, development of new and innovative technologies in the United States is leading to renewable and drop-in fuels, bio-based materials, and renewable chemicals that are replacing fossil-based products. The following specific efforts are being addressed: • Ensure consistent federal messaging • Increase federal agency coordination • Recognize opportunities for improvements across the supply chain • Integrate diverse national goals and objectives linked to the sustainable bioeconomy • Coordinate stakeholder interests and actions in both the public and private sectors	Link here[143]
18	The Bioeconomy, Climate Change, and Sustainable Development	Chum, H. L. 2016	Overarching presentation on bio economy strategies around the world and GHG mitigation	Link here[144]
19	Chemistry and Advanced Materials Industry Transformation Biotechnology Ecosphere in China	World Economic Forum 2016	The future of the bio-manufacturing industry in China is very positive. Achieving scale and unlocking the full potential of the biotechnology industry in a circular economy requires concerted effort from the industry at both the macro and micro level. At the macro level (within the country structure), design policies, systems, and enterprises enable a circular economy transition in growth regions. At the micro level (within corporate systems), important work remains to assess and understand the systems necessary to better integrate biotechnology companies into circular economy practices and the broader economic landscape. Policy/regulation: Focus on establishing stronger dialogue with the government to continue to drive the commercialization of biotechnology. – Feedstocks: Second generation feedstocks show great promise and will likely come from joint ventures. Cataloguing existing companies, reaching out, and establishing	Link here[145]

[143] https://biomassboard.gov/pdfs/farb_2_18_16.pdf
[144] http://www.nrel.gov/docs/fy16osti/66687.pdf
[145] http://www3.weforum.org/docs/IP/2016/CH/WEF_CH_Biotechnology_Ecosphere_in_China_2016.pdf

			contact may support them in their endeavours to develop technology and drive commercialization.	
20	An assessment of the potential products and economic and environmental impacts resulting from a billion ton bioeconomy	Rogers, J. N.; et al. 2016	Two alternative biomass availability scenarios in 2030, defined as the (i) Business-as-usual (598 million dry tons) and (ii) Billion Ton (1042 million dry tons), establish a range of possible outcomes for the future bioeconomy. Developing the integrated systems, supply chains, and infrastructure to efficiently grow, harvest, transport, and convert large quantities of biomass in a sustainable way could support the transition to a low-carbon economy. The paper's estimates show that developing biomass resources and addressing current limitations to achieve a Billion Ton bioeconomy could expand direct bioeconomy revenue by a factor of 5 to contribute nearly $259 billion and 1.1 million jobs to the US economy by 2030.	US market and roadmap for development of the bioeconomy
21	Policies impacting bio-based plastics market development and plastic bags legislation in Europe	Carrez, D. et al. 2017	Comprehensive report describing worldwide policy developments impacting bio-based economy, with a focus on plastics. The report points out that almost no country has dedicated policies on commercialising bio-based plastics or materials. The policies that exist are not binding, but more on R&D, creating awareness and establishing standards.	Commercial report, short version freely available[146]

[146] http://bio-based.eu/download/?did=88415&file=0

8.2.1 Key findings of the assessed studies

Developing integrated systems, supply chains, and infrastructure to efficiently grow, harvest, transport, and convert large quantities of biomass in a sustainable way could support the transition to a low-carbon economy (Rogers et al. 2016). However, for bioeconomy to become a key driving force of sustainability transformation in the circular economy, a more systematic, inter-sectoral and international approach is needed (Communiqué Global Bioeconomy Summit 2015).

As awareness of the bioeconomy's potential spreads, there is a great number of countries that are somewhat engaged in the development of a national strategy. The main emphasis is often to enhance the economy of a nation and provide new employment and business possibilities, whereas the aspects of sustainability and resource availability are addressed only to a limited extent (Staffas et al. 2013). This is achieved, across the globe, by nations investing in Public/Private Partnerships to expand their bio-based economy for domestic and international consumers (Golden et al. 2014).

An overview of countries with bioeconomy strategies worldwide has been compiled by the BioSTEP project and can be accessed through their website[147].

In the vast majority of countries that have bioenergy and biofuels policies, there is either no policy support for bio-based materials (especially chemicals and plastics) or it is limited to R&D subsidy (Philp 2015). However, material use still slightly outweighs energy use worldwide (Raschka et al. 2012). This is mostly due to traditional bio-based material uses, such as wood products, oleochemicals or paper and only slightly because an increasing number of countries are progressively focusing on a transition to a bioeconomy based on materials. For **South Africa**, for example, this represents a shift from developing the biotechnology sector to developing a bioeconomy, which is cross-disciplinary, and promotes holistic solutions and world-class innovation (Department of Science and Technology, Republic of South Africa 2014).

The increasing focus on a material-based bioeconomy facilitates access to raw materials by other industries, creating an increasing variety of potentially environmentally efficient products. The attractiveness of bioplastics as replacements for petro-based plastics, for instance, is dependent in part on their ability to meet environmental as well as economic goals. These are their sustainability, from production to end of life, along with job creation (OECD 2013). Despite these potential benefits, there are also many actual and potential barriers to the growth of a bioplastics sector. These are common to many other bio-based products and include difficulty in assuring a constant stream of biomass, lack of regulatory frameworks and critical mass for recycling, among others (OECD 2013).

The future of the biomanufacturing industry in **China** is projected to be very positive. However, achieving scale and unlocking the full potential of the biotechnology industry in a circular economy continues to require concerted effort from the industry at both the macro and micro level (World Economic Forum 2016).

China included the bioeconomy as a priority within its 12th Five-Year Plan for Energy Saving and Emission Reduction aiming to transform the mode of economic development, establish an energy saving and environmentally-friendly society, and strengthen the capacity of sustainable development.

In the 13th Five Year Plan (2016–2020), of 33 major targets listed in the document, 16 of them concern the environment and resource use. During the 5 years of the 12th plan, China has pledged to invest more than USD 316 billion in promoting energy-saving and low-carbon projects across the country. Also stressed in the plan is the need to accelerate China's bioeconomy to serve major needs in health, agriculture, and environmental protection. For the first time in a five-year plan,

[147] http://www.bio-step.eu/background/bioeconomy-strategies.html

China also set a target for the reduction of carbon intensity, which could also affect the plastics sector. The 12th Five Year Plan furthermore produced a Plan for Development of Bioindustry. Among its ambitions was that by 2015 China should produce 3 million tonnes of bio-based polymers. (Carrez et al. 2017)

While the **United States** is a global leader in promoting the use of sustainably produced feedstocks to fuel economic activity and growth, the bioeconomy is also still in its early stages (The Biomass R&D Board 2016). Much like elsewhere around the world, there are challenges facing the continued expansion of the bioeconomy such as reliable availability of raw materials with increased climate and severe weather impacts, water availability, and stability of the markets (Golden et al. 2014). The United States Department of Agriculture (USDA) BioPreferred program and Federally-supported research continue to drive investment in research and development (R&D) and make available broader sets of bio-based consumer products (Golden et al. 2014).

Outside the major bioeconomy hubs mentioned above, the bioeconomy tends to have a more local characteristic. As previously mentioned, the more common developments tend to focus on biofuels. However, an increasing number of bioeconomy strategies are picking up in Global South.

For instance, in order to ensure that the wealth of indigenous knowledge is used for the benefit of the people of South Africa, the nation will link bio-industry sectors with cross-cutting indigenous knowledge-based technology innovation programmes (Department of Science and Technology, Republic of South Africa 2014). Important focus is given to inclusive development, in India, by nurturing entrepreneurship aiming at protecting and promoting intellectual property, technology transfer, and SME support systems (Department of Biotechnology Ministry of Science & Technology Government of India 2015).

The oceans economy can also contribute to addressing some of the concerns associated with economic and environmental vulnerability, including those associated with remoteness, by fostering international and regional cooperation under an ‘ocean space approach’ (UNCTAD 2015) Bioprospecting of marine genetic resources offers interesting opportunities for benefit-sharing and creation of scientific capacities in **Small Island Developing States** (SIDS), especially in relation to pharmaceuticals, cosmetics and food products development (UNCTAD 2015).

In **Malaysia**, the palm oil sector generates the largest amount of biomass. Although currently, the vast majority of the oil palm biomass being generated today is returned to the field to release its nutrients and replenish the soil, there is also the potential to utilise this biomass for a variety of additional high value end-uses (AIM 2013). Utilising local biorefineries and cascading processes, there is the potential to retain in the field the portion of the biomass that has the highest nutrient value but the lowest downstream value, as represented by its carbohydrate content, and replace the balance with inorganic substitutes (AIM 2013). The development of partnerships is critical for mobilising the biomass, and the government has already put in place certain incentives and strategies to encourage development (AIM 2013).

Thailand is a biomass-rich country with significant feedstock resources, with more than 4,000 companies in the plastics industry. In 2006, the Thai Government declared the bio-based plastics industry one of Thailand’s strategic industries for which the government has vowed to push forward and promote sustainable growth and development. This resulted in 2008 in a “National Roadmap for the Development of Bioplastics Industry”, developed by the National Innovation Agency (Ministry of Science and Technology). This action plan for 2008–2012 focused on 4 main strategic areas: sufficient supply of biomass feedstock, accelerating technology development and technology cooperation, building industry and innovative businesses, and the establishment of supportive infrastructure. The strategies covered the entire value chain of the bio-based plastics industry. The roadmap provided targets, indicators and action plans and designated sectors and

organizations for implementing. The total budget for the roadmap strategies at that time was USD 60 million.

Examples of incentives for investment in bio-based plastics are: a corporate income tax exemption for eight years and additional 50% reduction for five years; deductions for infrastructure construction and installation costs; import duty reductions or exemptions for machinery and raw materials; permission to bring in foreign experts and technicians, etc. These government initiatives and incentives have led to several investments in production facilities by both international and domestic firms. The Thai government also encouraged Thai companies to engage with international bio-based plastics companies and promoted close collaboration with international partners. In addition to investment incentives, other government policies promoted the use of bio-based plastics and the development of Thai industrial standards for bio-based plastics and consumer awareness (Ministry of Science and Technology of Thailand, 2008).

More recently, the Thai Cabinet approved additional supportive measures to boost investments in this sector, such as a USD 10 million grant for the construction of a pilot bio-based plastic resin production facility. In addition to the pilot plant construction, the supportive measures for 2011–2015 to enhance commercial investments in the local bio-based plastics industry are targeting five areas: biomass availability, bio-based plastics R&D, standardisation system, business and investment privileges, and market promotion and environmental management. A total of USD 20 million has been committed by the Thai government to support the implementation of the supporting measures in these five areas. The development of the local bio-based plastics industry in accordance with the National Roadmap and the supportive measures is expected to result in economic value of over USD 204 million for the country. (Carrez et al. 2017)

Following the ratification of the Kyoto Protocol in 2002, the **Japanese** government announced two practical state measures to support the policy, i.e. the "Biotechnology Strategic Scheme" and the "Biomass Nippon Strategy". The main objective of the two strategies was to promote the utilization of biomass as a renewable source and to apply fast-advancing biotechnologies in order to reduce the consumption of fossil resources and to mitigate global warming. The Biomass Nippon Strategy (2002) was one of the earliest approaches to accessing local access to feedstocks by coordinated action of three Japanese ministries: the Ministry of Agriculture, Forestry & Fisheries, Ministry of the Environment, and the Ministry of Economy, Trade and Industry. The Biomass Nippon Strategy was revised in March 2006 to "accelerate biomass towns11" and to "promote the utilization of biofuels".

In the strategies, the expansion of use of biomass-based plastics is proposed. The policy objective stated in the Biotechnology Strategic Scheme is to replace approximately 20% (2.5 to 3 million tons per year) of conventional plastics with plastics from renewable resources by 2020. But these policy objectives were only non-binding targets to promote bio-based plastics without any specific regulation and the impacts were correspondingly low (Carrez et al. 2017).

The government of **South Korea** systematically supports green industries, including the bio-based plastics industry (Korean Bioplastics Association16). The following stimulating measures have been taken:

- Limit on use and free distribution of disposable bags;
- Act to promote saving and recycling resources strengthened
- Regulations on disposables (containers, cups and trays (except biodegradable materials)),
- Regulations on non-degradable disposable table cloths,
- Gradual annual reductions in synthetic resin-based packaging (except biodegradable materials),
- Waste treatment charge system to be enforced (except biodegradable materials)

8.2.2 Trends and policy approaches

If governments wish to realise a successful bioeconomy in the future, the case for supporting the production of bio-based chemicals and plastics, apart from biofuels, warrants serious attention. This is because a holistic approach to policy is more likely to lead to a successful bioeconomy, with governments avoiding creating policies in one area that may create policy problems elsewhere (OECD 2014).

Globally speaking, one option is to apply the policy support measures that are currently available to biofuels and bioelectricity to bio-based materials. The major policies that are most likely to stimulate investment in bio-based materials are quotas/mandates and tax incentives. Public procurement acts as a demand-side measure to stimulate market uptake. Another, potentially very effective, measure would be a planned phasing out of fossil fuel consumption subsidies (OECD 2014).

Creating programs to streamline and expedite the permitting process for biorefinery construction, along with co-funded and tax incentivised projects to construct new biorefineries, or to repurpose or retrofit existing idle or underutilized manufacturing facilities for the production of advanced biofuels and/or renewable chemicals, can be extremely successful policies (Erickson 2012; OECD 2013, Skinner et al. 2014). Ultimately, as market competitiveness is achieved, all forms of public support would be removed (Philp 2015).

To create state based campaigns to educate the public on the availability and societal benefits of industrial biotechnologies or to require state agencies to give purchasing preference to bio-based products during procurement cycles (Erickson 2012) are options that can trigger the development of advanced bioeconomy sectors.

In **Brazil**, as it is the case in many other countries, such as the US (Golden et al. 2014), there is a particular need for investment in physical infrastructure and human resources which, together with tax incentives for a high value added production, are part of the public policies that must be given priority by the government (Harvard Business Review 2013).

8.2.3 Discussion and identification of gaps

As the chapter on socio-economic impacts already discusses, there is a considerable gap in data on the impacts of the bioeconomy as a whole, even in Europe. This makes information gathering even more difficult for countries and regions in which bioeconomy is not covered by a publicly established policy. Some specific information on the markets of individual product groups can be found, depending on the activities of market researchers or industry associations, for example. Language barriers (e.g. for the Chinese market) pose another challenge. Based on the publications we analysed, it can be said that dominance of major bio-based markets is still exercised by North American and European companies. However, there is a great surgence of Asian companies expected, gaining relevance in certain areas and leading to Europe and the US losing relative market shares.

9 Social benefits and consumer acceptance

9.1 Consumer awareness, acceptance and trends

Table 31: Studies on consumer awareness, acceptance and trends

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	Report of market acceptance of bio-refinery concepts amongst consumers[148]	Kurka, S., Menrad, K., 18 May 2009	Survey study on acceptance of biorefineries among consumers from six EU countries (Germany, Netherlands, UK, Sweden, Greece and Poland). Attitudes towards biorefineries were found to be more positive than towards pure biofuels plants, and both were seen as more positive than petroleum refineries. More specific aspects such as eco-friendliness, commercial viability and impact on food prices by biorefineries were also rated by consumers. Furthermore, motivations for buying bioplastic products were investigated, finding ecological motivations to be the strongest in influencing theoretical buying decisions for bioplastics goods. Level of knowledge on bio-based economy assessed and found to be quite low; buying frequency of different bio-based products also assessed. When asked about their willingness to pay for bio-based products (examples: dish-washing detergents and shampoos), respondents from all countries indicated to be willing to pay higher prices.	Deliverable of the BIOPOL project; due to publication date (2009) out of scope of the study, but unique in terms of perspective on biorefineries as far as we could find.
2	DuPont Green Living Survey: China[149]	Environics Research / DuPont; 2012	Assesses consumers' and entrepreneurs' perceptions in terms of environmental economic behaviour in China. Biobased products are equalled to biodegradable products in the survey. Less than half of consumers claim to be at least somewhat familiar with green household products. Confidence in the green claims grows with higher familiarity. 70% of Chinese consumers are confident that green products are better for the environment. 30% of consumers have heard the term "biobased" most commonly about personal care products and textiles. Majority of consumers believe that bio-based products are of the same or of better quality than comparable petro-based products and are willing to buy such products. Manufacturers see increasing value for products with environmental benefits and rate issues such as "safer materials", "reduced air/water pollution" and "reduced energy use" as highest amongst the important green aspects.	Focus: China

[148] http://www.biorefinery.nl/fileadmin/biopol/user/documents/PublicDeliverables/BIOPOL_D_2_1_3b_-_Final_180509.pdf
[149] http://biosciences.dupont.com/china-green-living-survey/

3	Biomasse-basierte Produkte aus Konsumentensicht[150]	Kurka, S., 02 May 2012	This dissertation assesses the willingness to pay (WTP) of consumers in three European countries (Germany, Sweden, Netherlands) for bio-based shampoos and washing up detergents. In all three countries, majority of participants indicated that they are willing to pay a higher price (between 8% and 15%) for both product groups. The dissertation then makes an estimate, based on a regression model, of what the most important influencing factors for WTP are: Sensitivity to oil price developments and scarcity of raw materials; health and environmental consciousness.	available in German only (dissertation)
4	AOCS Sustainability Survey Results: A different angle (Part 4)[151]	DuPont 2012	Survey assesses industry experts' beliefs on consumer attitudes towards 'green' products among Asian, European and North American consumers. The biggest barrier to consumers purchasing 'green' products was thought to be the perception of higher cost, followed by a low awareness or understanding and the perception of reduced quality. The trend to purchase 'green' products was most pronounced with food, detergents and appliances. The top three criteria that make detergents 'green' for consumers across all regions were believed to be natural ingredients, shorter cycles and lower temperatures. North America is the region least confident that consumers view product sustainability as important when making a purchase.	
5	Green Living Survey: India 2014. Consumer Awareness and Adoption of Biobased Products[152]	DuPont 2014	Survey among Indian consumers about 'green' products. Majority of participants were aware of what 'green' products are and feel confident that they are better for the environment. 67% of participants indicated that bio-based ingredients enhance the desirability of a product.	Focus: India
6	GreenPremium Prices Along the Value Chain of Bio-based Products[153]	Carus, M., Eder, A., Beckmann, J. 2014	Survey, interviews and literature analysis of GreenPremium prices for 35 bio-based chemicals, polymers and plastics. Results show that GreenPremium prices do exist and are paid in the value chains of different bio-based chemicals, polymers and plastics – especially for new bio-based materials and in the European market. Large majority indicated that their customers would be willing to pay a premium price between 10 and 20%, but even 11% indicated that a premium price of more than 50% would be acceptable, too. Interestingly, the GreenPremium is often highest (or even existent) in the B2B stages of a value chain, end consumers are often not concerned by the GreenPremium (example: the plant bottle does not make a bottle of CocaCola more expensive for end consumers, but the bio-based constituents are sold at a premium of up to 80% in the value chain).	nova study A 2016 update of the study confirmed the findings

[150] https://mediatum.ub.tum.de/doc/1086928/1086928.pdf
[151] http://biosciences.dupont.com/fileadmin/user_upload/genencor/documents/15501480_DuPont_AOCS_Survey_Results.pdf
[152] http://www.dupont.com/content/dam/dupont/products-and-services/industrial-biotechnology/documents/DuPont Green Living Survey_leave behind_2209.pdf
[153] http://www.bio-based.eu/nova-papers

7	Exploring Green Consumers' Mind-Set toward Green Product Design and Life Cycle Assessment	Lemke, F., Pereira Luzio, J.P. 2014	Targeted question on how already green consumers from Portugal and Brazil perceive the specific items of green product design and LCA, assessed by in-depth interviews. The analysis suggests that there are still important gaps between what green consumers demand and what businesses are currently able (or willing) to supply. Scepticism of greenwashing is still very prevalent, and the most effective tool to counter this seem to be third-party verified certifications and labels, EU Ecolabel is mentioned specifically.	in: Journal of Industrial Ecology, Volume 18, No. 5; NO focus on bio-based
8	Acceptance factors for bio-based products and related information systems[154]	Meeusen, M., Peuckert, J., Quitzow, R. 2015	Assesses acceptance factors for consumers, businesses, public procurers and NGOs both in surveys and focus group discussions. With regards to consumers, the study found a high degree of unfamiliarity with the concept of bio-based products in the six EU focus countries: Germany, The Netherlands, Italy, Slovenia, Denmark and Czech Republic. They have positive associations linked to the environment. However, there are also mixed and negative feelings due to the lack of knowledge and arising questions about the bio-based concept and products. Discussing seven specific bio-based products showed that each product is perceived in its own way. For every product it is important that one's personal benefits are fulfilled first. The bio-based element is perceived as only a small additional positive aspect. Regarding the labelling of bio-based products, consumers seem to prefer bio-based products with a label.	Deliverable 9.2 of the Open-Bio project
9	The Sustainability Imperative: new insights on consumer expectations.[155]	Nielsen N.V., 2015	Report finds a strong commitment of consumers to sustainable products and brands; survey conducted online in 60 countries worldwide. It states that in the year before the study (2015), sales of consumer good from brands with a demonstrated commitment to sustainability rose more than 4% globally, while those without grew less than 1%. 66% of consumers say they are willing to pay more for sustainable brands.	No specific focus on bio-based
10	Consumers' Willingness to Pay for Durable Biobased Plastics Products: Findings from an Experimental Auction[156]	Kainz, U. 2016	This dissertation poses and answers five questions: 1) What do consumers know about biopolymers? 2) What information about biopolymers is relevant to consumers? 3) Are consumers willing to pay more for biopolymer products than for plastic products made from fossil fuel? 4) How does information about biopolymers affect consumers' WTP? 5) Do attitudes towards sustainable consumption and prior familiarity with biopolymers affect WTP? 60% of respondents associated the terms "biopolymers" with "being made from renewable resources" and most consumers have positive connotations. Consumers are somewhat concerned with land use and food competition.	Dissertation, consumers assessed in Bavaria, Germany

[154] http://www.biobasedeconomy.eu/research/open-bio/publications
[155] https://www.nielsen.com/content/dam/nielsenglobal/dk/docs/global-sustainability-report-oct-2015.pdf
[156] https://mediatum.ub.tum.de/doc/1293618/document.pdf

			In an experimental auction, the study assessed WTP for biopolymers in a simulated market place for the exemplary products sunglasses and a toothbrush made from durable bio-based plastics. WTP for those bio-based products was higher than for the conventional product equivalent. Labels increased trust, but information on climate friendliness or durability did not significantly affect WTP.	

9.1.1 Key findings of the assessed studies

There is limited availability of studies that cover the specific topic of consumer perception of bio-based products, which is why this analysis also included a few studies that were out of scope timewise (Kurka & Menrad 2009) or did not have a dedicated focus on 'bio-based', but covered topics such as sustainable or 'green' consumers. In terms of focus on the topic at hand – trends of the bio-based economy – the three studies marked in green in the table (Carus et al. 2014, Meeusen et al. 2015 and Kainz 2016) are recommended by the authors as being most helpful and enlightening. The geographical focus of the studies differs: Several studies analyse consumer groups from a number of EU-28 countries, some only refer to a specific nationality (e.g. Germany). The DuPont studies assess broader regional trends, e.g. North America, Europe and Asia. Due to these different approaches and focal points, a comparison of consumer perception between different regions is only possible within one study, in case the study applies such a comparison. A comparison across different studies is not possible from a methodological point of view.

9.1.1.1 Level of familiarity of consumers ("awareness")

Most studies assess the **level of familiarity** of consumers with bio-based products. The findings indicate that although especially in the newer studies more and more respondents are aware that the term 'bio-based' refers to the feedstock base (e.g. 60% of respondents in Kainz 2016), there is **still a lot of confusion about the exact meaning of the term** as well as its implications. Predominant issues that are often automatically associated with 'bio-based' are for example 'biodegradable' or 'organic' (the latter being a definite issue with German consumers; for other countries this has not been well established).

While the different DuPont surveys (2012 and 2014) claim a relatively high awareness of bio-based products, the Open-Bio project found this to be much lower. Here, a look at the details of the survey helps to understand potential reasons for this discrepancy: The DuPont surveys talked about 'green' products which were automatically equated with 'bio-based' products in the communication with consumers. This in itself is at least partially misleading, which is why the results of the surveys need to be interpreted with caution. The Open-Bio project stuck to a much narrower definition of bio-based products[157], which was not well known to consumers.

In general, there seems to be growing familiarity among respondents to such surveys about what constitutes a bio-based product. While in Kurka & Menrad 2009, the authors assumed automatically that bioplastics would not be known to consumers and provided a definition of the term, later studies rather asked about the existing knowledge and – as mentioned above – found familiarity levels of up to 60% of consumers (Kainz 2016). With all of the voluntary studies it should not be forgotten that a self-selection bias can play a role, too, meaning that only persons who are already interested in the topic choose to participate in such surveys.

9.1.1.2 Willingness to pay (WTP – "acceptance")

A number of studies tries to assess the acceptance of consumers of bio-based or green products by evaluating their willingness to pay higher prices for such products. This higher price is also called "GreenPremium". Almost all studies found a WTP higher prices, both by end consumers as well as by businesses in the value chain of bio-based products. Kurka 2012

[157] See EN 16575: Bio-based products – Vocabulary. August 2014.

found a WTP of 8%-15% more than the usual price for a bio-based product, while Carus et al. 2014 assessed the most acceptable GreenPremium in several bio-based value chains to be between 10-20%. In terms of methodology, it needs to be carefully differentiated whether studies assess the theoretical WTP (Kurka & Menrad 2009, Kurka 2012, Meeusen et al. 2015, Nielsen 2015), an experimental WTP in a semi-real market place environment (Kainz 2016) or assess experts' experiences throughout the value chain (Carus et al. 2014).

Most studies found that bio-based products are associated with environmentally friendly products, resulting in mostly positive connotations, for example Kainz 2016:

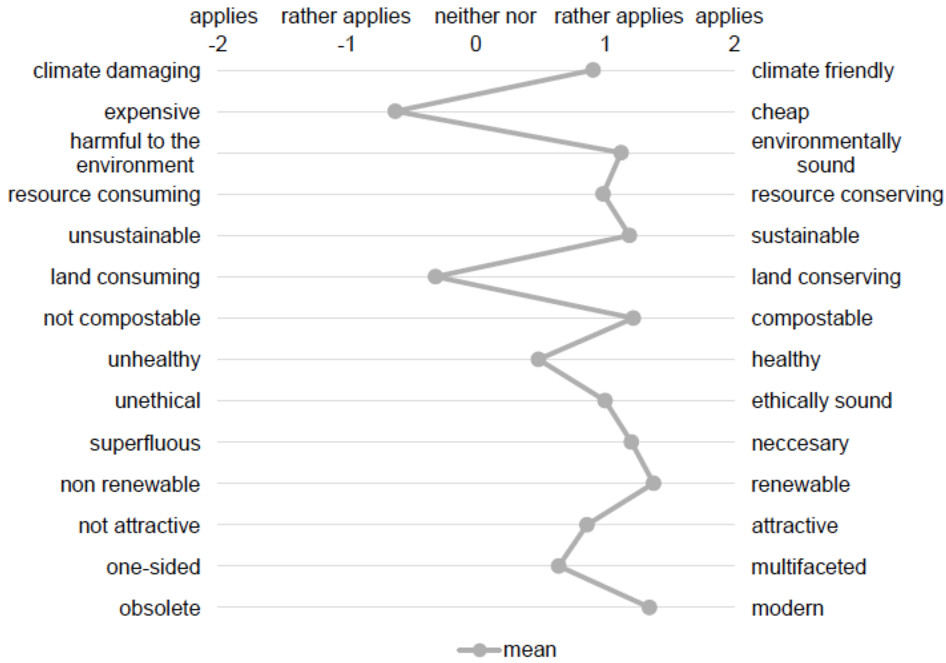


Figure 47: Consumers' perception of biopolymers
(Kainz 2016, p. 48)

From this analysis, it becomes clear that the only negative points in the perception of biopolymers are price and land use.

Meeusen et al. assessed both positive and negative connotations of bio-based products:

Figure 48: Positive connotations of bio-based products
(Meeusen et al. 2015, p. 22)

Figure 49: Negative connotations of bio-based products
(Meeusen et al. 2015, p. 23)

This confirms that most of consumers' positive associations with bio-based products lie in the areas of environment, sustainability and health. However, also the negative associations are similar: Price and product quality are predominant concerns, but also scepticism about claims seems to be an issue. The latter was also found in Lemke & Pereira Luzio 2014 as a general issue among green consumers. However, the general tenor of the analysed studies is that **most consumers see bio-based products overall positively**.

9.1.1.3 Sustainability and information requirements ("trends")

The most important trend seen among consumers in general is a trend towards more ecologically conscious, 'sustainable' consumption. This goes hand in hand for increased information requirements about products in order to make an informed buying decision (Lemke & Pereira Luzio 2014, Nielsen 2015). Seeing as the topics of environmental friendliness and sustainability seem to strongly influence the discourse with consumers, the topic of information requirement is therefore highly relevant. Unfortunately, only one of the analysed studies dealt with this topic in more detail (Kainz 2016). First, consumers were asked to rate their need for information on different aspects related to biopolymers:

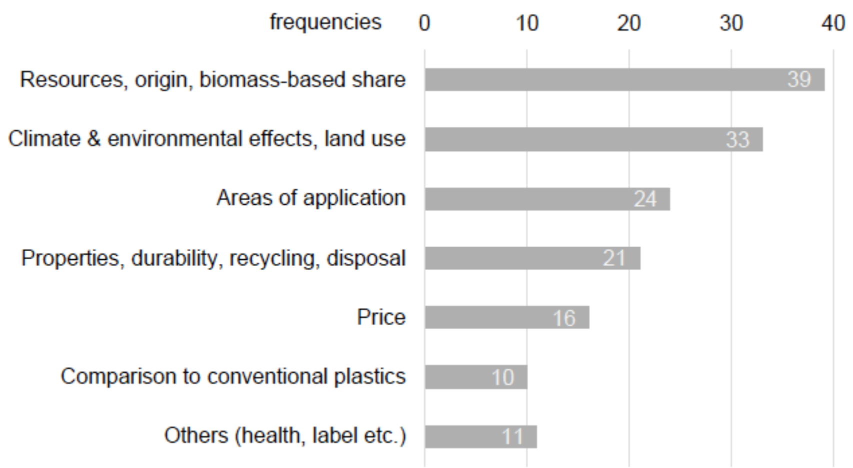


Figure 50: Requested information about biopolymers
n = 77 (Kainz 2016, p. 52)

Between several rounds of bidding for the bio-based products in the experimental auction, different groups of participants were then offered additional information on biopolymers in different forms and it was measured how that affected their WTP. One of the main conclusions from the study is **that information in the form of texts or similar did not have any impact on the consumers at all**. Labels, however, did have some positive influence on the WTP as they seem to increase trust, with at least half of the participants:

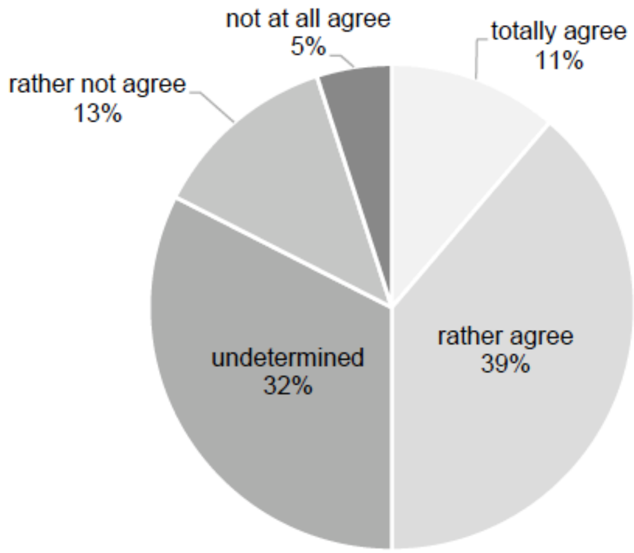


Figure 51: Influence of label „Renewable Resources“ on trust in offered products (Kainz 2016, p. 63; Responses to statement „The label increased my trust in the offered products“, n=80)

Also other consumer studies stress the need for independent, third-party verified certifications and labels, sometimes mentioning the EU Ecolabel especially as being trustworthy (Meeusen et al 2015, Lemke & Pereira Luzio 2014).

9.1.2 Discussion and identification of gaps

The above analysis illustrates several interesting points that can serve as a basis for further study. First of all, almost all consumer research on bio-based products **focuses on issues such as sustainability or 'green' products**. This is on the one hand understandable, since the term 'bio' is in many European countries by now automatically associated with something positive for the environment and since manufacturers of bio-based products often aim to achieve GreenPremium prices for their products (and succeeding, as shown by Carus et al. 2014). On the other hand, this is quite one-dimensional and can even be dangerous. For once, this kind of research completely ignores that **consumers could favour bio-based products if they provide improved functionalities without any added environmental benefits**. And if marketing and consumer communication focus too much on these topics alone, it can bear the danger that bio-based products which do not demonstrate clear environmental benefits (but may provide excellent properties or show other advantages) are vulnerable to scepticism by consumers fuelled by unrealistic expectations.

Furthermore, most of the research equals "acceptance" with the willingness to pay higher prices for bio-based products. While it might be the reality in many cases that bio-based products are more expensive than their conventional counterparts, it would be misleading to conclude that a lack of willingness to pay these higher prices is somehow related to a lack of acceptance of bio-based products. Rather, the only valid conclusion from this fact would be that the resource base is not a decisive factor for a buying decision ("consumers do not care" instead of "consumers are sceptical of bio-based products") and that therefore price is a much stronger motivator for consumers. **It would be indeed interesting to assess whether the average consumer is aware of the resource base of a conventional product in order**

to provide a valid basis for comparing acceptance. As far as could be seen, none of the studies above made an attempt to evaluate this.

While many studies in this field come to the conclusion that transparent information is key to motivating consumers to buy bio-based products, the surface has barely been scratched when it comes to assessing which information is necessary and in which form it should be presented. Nowadays, consumers are confronted with an extreme multitude of products from which they need to choose in combination with an excess of information available to everyone who wants to look for it. In the context of discussions about attention economy, it seems to be a crucial question on how to package and present information on bio-based products in order to catch consumers' attention and convince them of the benefits of such products. **There is tremendous room for further work in this area, which will probably also require more in-depth and qualitative analyses of how consumers perceive certain issues around bio-based products and what motivates or hinders them to buy those products.** Kainz 2016 made a first attempt in assessing the different impacts of several forms of information and found independent, third-party verified labels to be the most positively influential on buying decisions.

9.2 Product properties and functionalities

Table 32: Studies on improved bio-based products' properties and functionalities

No.	Title of the publication	Authors & Date	Synopsis	Further comments
1	Bio-based plastics: status, challenges and trends	Storz, H., Vorlop,K., 2012	This article reviews advances in production processes and material properties of selected bio-based plastics. It focuses on the most important bio-based plastics with established production and commercial applications. This article concludes by saying given the current price differences of conventional and bio-based plastics, one can assume that bio-based and conventional plastics will be used side by side in the foreseeable future.	Landbauforschung[158]
2	Bioplastics boost packaging film and paper barrier and performance	Lingle, R., 2015	This article talks about how bioplastics boost the barrier performance of packaging films and papers. The paper concludes by stating the positive effects of bioplastics such as modifying ductility and toughness in footwear, packaging etc.	Metabolix Article[159]

[158] http://literatur.ti.bund.de/digbib_extern/dn053246.pdf
[159]http://www.packagingdigest.com/sustainable-packaging/metabolix-engineers-bioplastics4improved-performance1505

3	Modified Vegetable Oil Based Additives as a Future Polymeric Material—Review	Nikesh, B., Samarth, A., 2015	The paper gives a fundamental description of the various vegetable oil applications in polymer materials and their recent developments. Particular emphasis is placed on the study of the main applications of triglyceride based additives for polymer and to give the reader an insight into the main developments.	Institute of Chemical Technology, Mumbai, India[160]

[160] http://file.scirp.org/pdf/OJOPM_2015010908580751.pdf

9.2.1 Key findings of the assessed studies

Most of the knowledge we were able to find is on vegetable oils based chemicals and their functional applications. One of the studies lists major functionalities of vegetable oils and their derivatives as shown in Figure 1 below.

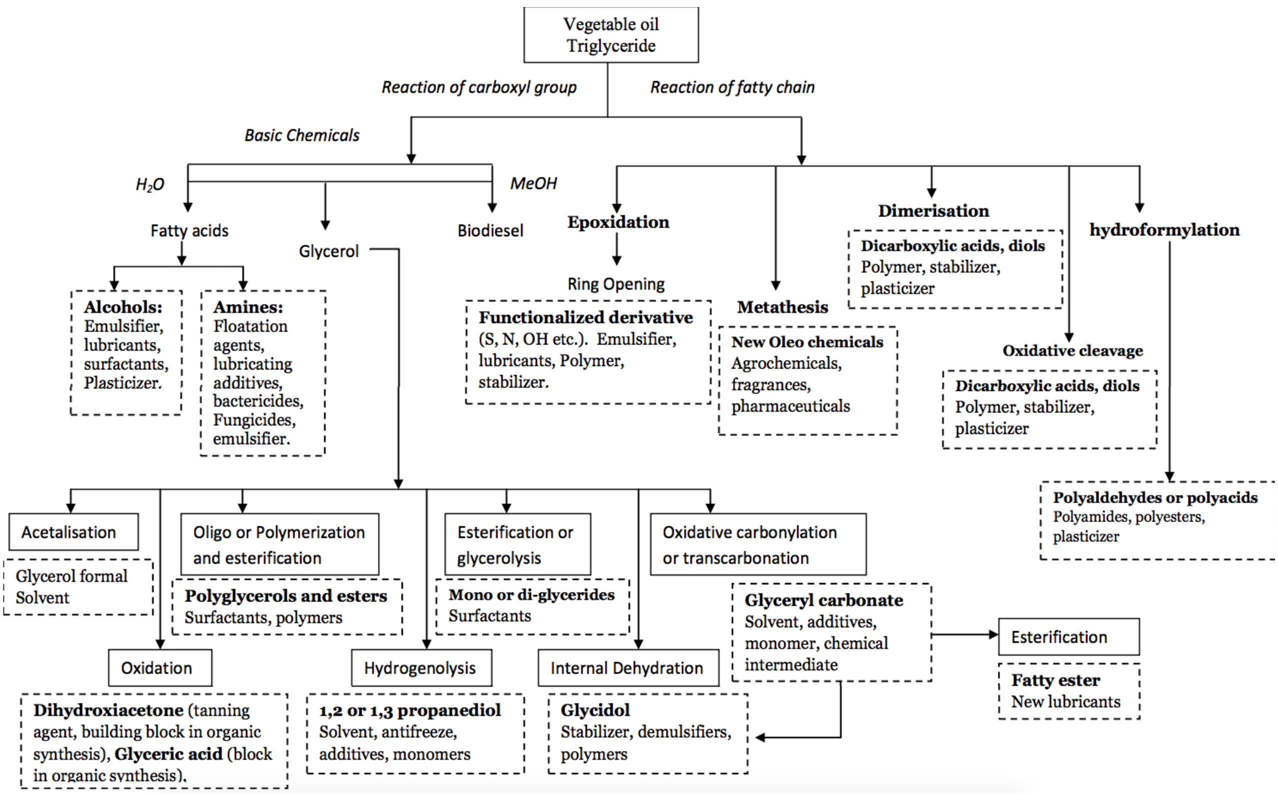


Figure 52: Routes for the preparation of valuable products from fats and oils
Source: Nikesh & Samarth 2015

The petrochemical based industries sell chemicals based on their functionalities. For example, adhesion promoter is a functionality of a chemical and it is sold as such to different end-uses such as construction, personal care or food etc. Most of the studies dedicated on functionalities in the bioeconomy consider plastics as the end user industry. Both studies listed are also on the functional application in the plastic packaging industry.

9.2.2 Discussion and identification of gaps

Apart from the topics of plastic packaging additives such as resin binders, the studies are lacking in a wide range of areas on bio-based products as functional products. The studies mainly focus on applications listed in previous chapters such as packaging, construction, textile and automobile, but not on the functional properties of chemicals such as dispersion agent, rheology modifiers, defoamers etc. The often-repeated claim that bio-based products offer additional functionalities to end consumers could not be substantiated by scientific studies within the scope of this report. As of now, the evidence base is mostly restricted to claims by companies, but not supported by independent third-party scientific research. In a multitude of cases, this is completely justified, since safety, environmental and functionality

issues are often regulated through well-established industrial processes, such as REACH, safety certifications and others. Here, it might be more an issue of communicating these to the consumers and the wider public in a credible way. In some other cases, e.g. when it comes to biodegradation, the authors suggest that better guidelines and research are necessary (see also Chapter 6 on policy).

This identified gap provides ample opportunity for follow-up and extended research. If added functionalities could be independently confirmed through research, this would facilitate both consumer communication and policy design – which could even lead to improved legislation on e.g. environmental issues that can be beneficial to the bio-based industries.

10 Final remarks

The study has shown that the state-of-art of research into the bio-based industries is of very different quality and differently advanced, depending on the sectors and sub-sectors in focus. The bio-based economy as a whole is a multi-faceted and rapidly changing business and any snapshot of a status quo will contain a certain degree of vagueness (also depending on language availability – there might be a significant amount of studies in Dutch, Italian, French etc. that were not in the focus of this analysis).

Some things, however, became quite clear. Despite the growing number of studies in many sectors, some issues still remain controversial. Especially with a view to biofuels, the suggested competition between food vs. fuel or the climate change mitigation potential of wood-based fuels are still hotly debated in science. It remains to be seen whether these issues can be resolved with further research.

Interestingly, some of the industries which have been traditionally relying on bio-based resources, do not see themselves as being part of the overall “bio-based economy” which has been in focus only more recently. Some examples of this are the textiles sector and the automotive sector (which, to be fair, only relies to a very limited extent on bio-based raw materials). This can act as a market entrance barrier for improved bio-based materials, since awareness is lacking and innovation will not be targeted towards these sectors, even though they might have high potential, e.g. for innovative bio-based textile fibres.

The most important gaps that were identified in this study are:

- Information, data, methodologies, impact assessments, standards and norms and incentive systems are much more developed in the field of bioenergy and biofuels in comparison to the industrial material use of biomass.
- There is no methodology that allows for an overarching comparison of ecological impacts of various bio-based materials. Established LCA methodology only allows conclusions pertaining to specific applications and only in comparison with specific counterparts. This makes it impossible to make claims about the environmental benefits of the bio-based industries as a whole.
- With regard to biodegradability, there is a large gap in both research and legislation.
- There is a lack of studies on food and feed additives, which are often named as important applications of bio-based materials in various strategic documents.
- There is a lack of evidence on improved properties and functionalities of bio-based materials in published scientific studies, which can lead to a lack of awareness and credibility.

This last point – added properties of bio-based materials – is of crucial importance. While there is a number of bio-based materials that provide consumers with true benefits (e.g. through reduced toxicity of plasticisers or improved cleaning performance of detergents), this is often only made known through company statements or consumer test magazines. Independent scientific studies confirming these claims could help to improve the image of bio-based industries and in a second step could even be the basis for improved implementation strategies and legislation that benefit both the environment and the people, while offering opportunities to bio-based industries. This provides ample opportunity for further research and action.