Circular bioeconomy:

The business opportunity contributing to a sustainable world

Powered by

Contents

Executive summary

The economic opportunity for bio-based products to complement or even substitute conventional ones is estimated to be USD $7.7 trillion by 2030 for food and feed waste,[1] products, and energy. Transformation toward a circular bioeconomy is crucial to solving our most pressing societal issues, ensuring companies have the required resources to produce goods and services and continuing to create value in the long-term.

Despite the increasing awareness of a need for a more circular economy, our world is only 8.6% circular, with this number notably below 9.1% in 2018.[2] The predominant economic systems remain based on a "take-make-waste" mentality and the increasing overexploitation of resources. This extends into non-renewable resources such as minerals and fossil fuels as well as renewable resources such as wood. Using natural resources beyond the regenerative capacity of our planet poses devastating risks for all living organisms. Climate change, biodiversity loss, land-use change, food loss and waste, as well as resource scarcity are some of the most urgent societal issues our generation is facing and demonstrates the finite nature of our planet's biocapacity. We are exceeding our planet's limits and a thoroughly changing of the way we produce and (re)use resources to survive is needed.

One solution is a transformation to a new economic system based on extending the use of resources to a maximum, via a circular economy "take/recycle-make-reuse/recycle" principle. In a perfect circular economy, resources are endlessly cycled in a closed loop through continuous reuse and recovery. However, in practice, some resources are lost through inefficiencies and technological or physical limitations. Replacing non-renewable resources with renewable resources, while ensuring that the new resources used can be regenerated by earth in a sustainable manner, has the potential to allow us to stay within the limits of our planet's capacity. This solution is called a circular bioeconomy.

From an economic perspective, a transformation toward a circular bioeconomy makes business sense. Expected growth is particularly high within non-food industries, such as products and energy, where growth from 2018 to 2030 is expected to be 3.3% per annum, leading to USD $5.5 trillion by 2030. This growth is based on an increase in the use of biomaterials within different product industries, the main ones being pharmaceutical, textiles, building materials, and packaging.

However, despite the vast economic and environmental benefits of a circular bioeconomy, certain barriers still stand in the way of the necessary transformation. Based on several interviews with businesses engaging in the industry, we found that the main barriers are:

- Financial flows (particularly additional costs)
- Technology
- Policy and regulation
- Mindset and values, due to the existing negative public perception of bio-based materials

To change the public perception and evaluate potential trade-offs, four principles were developed to guide companies in assessing the sustainability performance and economic viability of a new product: circular bioeconomy principles, environmental value, societal value and corporate and stakeholder value. These principles are broken down into a high-level checklist that provides companies with the critical questions to ask—ranging from the evaluation of the circularity[3] to potential negative environmental externalities to safeguarding societal values to ensuring economic viability.

Companies that adjust their businesses now not only show responsibility toward the environment but also create a long-lasting competitive advantage when externalities are priced in. Ultimately, this translates into benefiting from an untapped, growing business potential. This report includes examples of such front-runner companies, and acts as a roadmap for companies who are ready to join these leaders on the journey toward a circular bioeconomy.

However, businesses alone will not be able to generate lasting change across all sectors. Regulators, investors, and consumers must also support this journey toward closing resource loops. Only by working together can the urgently-needed societal benefits and substantial USD $7.7 trillion economic opportunity of bio-based products be realized.

① Introduction

1 Introduction

THE WORLD IS MORE THAN 90% LINEAR AND NEEDS TO BECOME MORE CIRCULAR

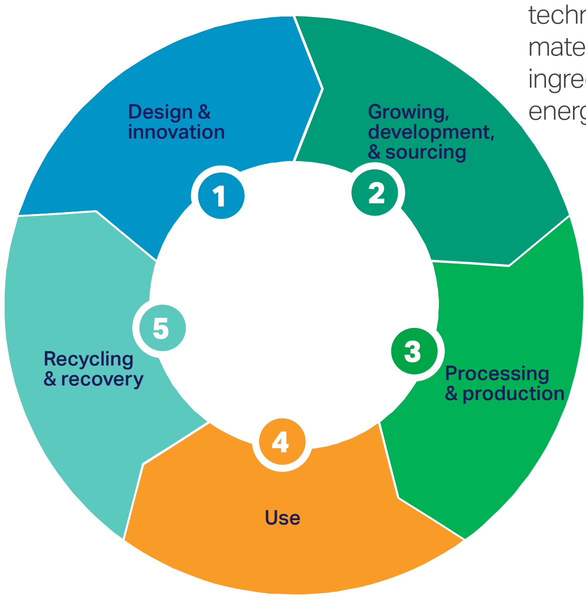
Our current economic systems are based on linear value chains that depend on a continuous and increasing extraction of raw materials and a disregard for them after use. Currently, only 8.65 billion tonnes of raw material—an equivalent of 8.6% of total material extracted—is cycled back into the economy, closing our resource loops. The other 92 billion tonnes of raw materials required to fuel our economies are extracted from earth, processed, used, and then discarded without any opportunity for recovering the materials.[4] One result of low recycling rates is the pollution of our environment with products and materials that do not biodegrade. Despite the increasing environmental awareness, the levels of circularity are deteriorating on a global level - dropping by on average 0.25% points over the last two years[5] - and the trend of increased overexploitation of natural resources is expected to worsen due to further population growth, increased income and spending power, as well as technological advances.

Our linear systems have devastating impacts on biodiversity loss, ecosystem services, and climate change. The loss of species is estimated to be between 1,000 and 10,000 times higher than the natural extinction rate.[6] A total of 62% of global greenhouse gas emissions are emitted during material extraction and processing, and the trend is increasing.[7] To reach the 1.5°C target of the Paris Agreement, we need to ensure net zero emissions by 2050.[8]

To reduce carbon emissions and enable sustainable production cycles, we need to act with urgency and move away from the traditional "take-make-waste" economic model toward one that is regenerative by design. The goal is to retain as much value as possible from resources, products, parts, and materials to create a system that allows for long life, optimal reuse, refurbishment, remanufacturing, and recycling/recovering - a circular economy.[9]

Businesses have a major responsibility to act. To support the circular change, they can transform their value chains into true value cycles at five different steps, (see Figure 1).

Figure 1: Business can tackle the value cycle at five steps



Design and innovation: Apply circular ideas or technologies when developing new products.

Growing, development and sourcing: Use innovative technologies to develop materials and product ingredients with less resources, energy, and chemicals.

Processing and production: Enable the production of goods with fewer resources, lower emissions, and based on renewable (energy) sources.

Use: Allow increasing the life span of a product, repurpose used products for other applications, and move away from traditional ownership to service models.

Recycling and recovery: Repurpose waste from one used product to feed into the production of another, fully functional product of similar or higher value, thereby leveraging what is considered waste as valuable secondary raw material or byproduct.

THE INCREASING IMPORTANCE OF BIO-BASED PRODUCTS IN THE FUTURE

Starting to circulate the resources we extract from earth is only solving part of our current problem. The type of materials used play a crucial role in safeguarding future sustainability. Based on current estimations, we will need twice the amount of today's materials by 2060—estimated to be 167 billion tonnes.[10]

COVID-19 has an ongoing effect on global economic activity and will continue to do so in the near future. As the world is learning to adapt, reliable projections about the mid- and long-term effects on economic growth, resource needs, and greenhouse gas emissions in a post-COVID-19 world are not yet available. Even though the COVID-19 outbreak has slowed down economic growth momentarily and might decrease the amount of resources needed in the next years, it has not fundamentally changed the linear nature of our economic system. This unchanged principle means that economic growth will in most cases correlate with increased resource needs. Where the effects of COVID-19 are reasonably well understood, they are discussed in this report. In all other cases, pre-COVID-19 projections were left in place, as they illustrate the expected developments.

Apart from the general influence on economic growth, COVID-19 also presents challenges and opportunities for the circular bioeconomy. As global supply chains are under pressure, sourcing locally produced renewable materials as opposed to globally sourced non-renewable materials has become more favorable, and the pressure to "build forward better" is incentivizing companies to change. An inclusive and green recovery is vital if we are to create more resilient economies and a world in which businesses can thrive with longevity and where nine billion people live well within the boundaries of the planet by 2050. There are positive signs that, in some countries, bailouts and stimulus packages have been designed with these criteria in mind. Additional challenges will include the increased awareness for hygiene standards. These will be applied to renewable and non-renewable materials alike, but non-renewable materials, including plastic, are often perceived as more hygienic. Consequently, increased awareness of hygiene standards may be leading to an increased demand for non-renewable materials such as those used for personal protective equipment.

For the shorter-term growth until 2030, biomass as raw material is expected to increase by 13% to 26.1 billion tonnes, while fossil-based materials are expected to increase by 20%, equaling 82.8 billion tonnes.[11] It is likely that this trend will not be essentially changed by COVID-19. Our current and future economic systems are not only of linear nature but also highly dependent on finite biocapacities. There is a certain carbon budget available to limit global temperature increase to 1.5°C and avoid the worst effects of climate change. Scaling up the use of bio-based materials across industries is critical to stay within our existing carbon budget.

Bio-based raw materials come from three main sources. Over 80% come from agriculture, 18% come from forestry, and only around 1% are based on aquaculture ingredients. This ratio is expected to remain similar during the next years. Currently, 70% of bio-based raw materials are utilized for food, beverage, and animal feed, while the remaining 30% are used for energy production and products. Within the latter category, biomass usage for construction is expected to almost triple and for packaging to more than double, thus representing the categories with the highest growths (see Figure 2).

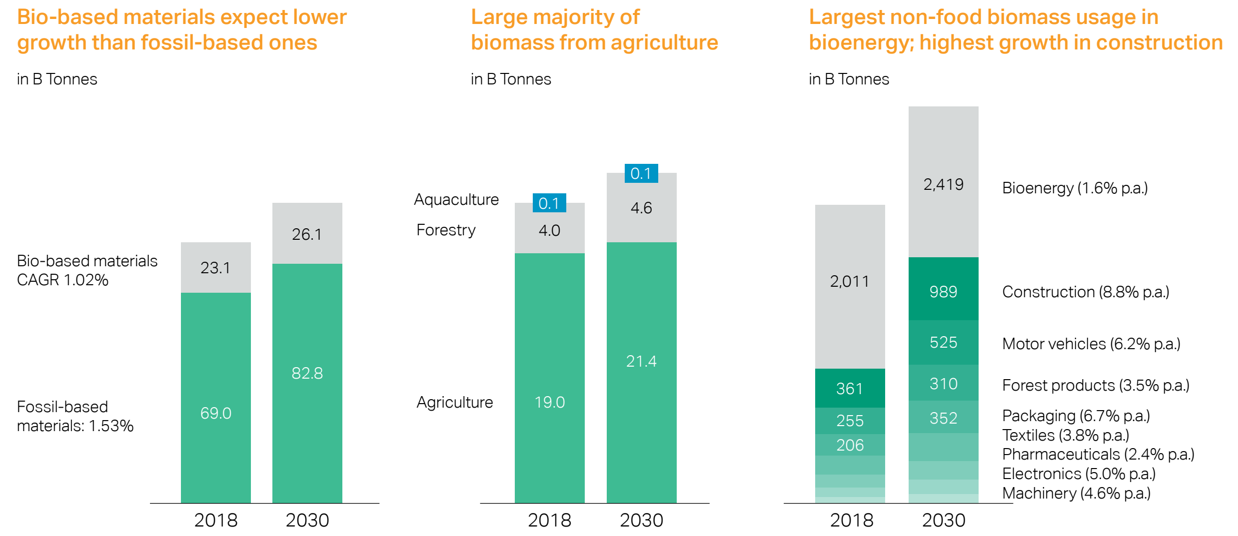
THE CIRCULAR BIOECONOMY PROVIDES MULTIPLE ECONOMIC AND ENVIRONMENTAL BENEFITS

A circular bioeconomy is based on renewable, biological materials and at the same time maintains the value of materials at their highest level, for as long as possible. The concept aims at enhancing the core value of a circular economy – resource loops can be fully closed, secondary biomass usage will be maximized, and new raw materials can be regenerated by nature without depleting existing stocks.

The benefits of a circular bioeconomy are multifold and the substitutional and complementation potential for food and feed waste,[12] products, and energy is estimated to create a USD $7.7 trillion business opportunity by 2030.

Improved financial performance. For businesses, a circular bioeconomy can help improve financial performance and company growth rates, for example through serving new markets and customer segments or increasing market share in existing industries. A pulp and paper company expanding its business by selling wood cellulose to a textile company to make compostable or fully recyclable clothes allows the forest company to expand into a new market, while the textile company taps into the environmentally-conscious customer segment.

Figure 2: Role of bio-based materials in shaping the future of production across industries



Source: Eurostat; OECD; WU Vienna; BCG analysis

Risk mitigation. By engaging in a circular bioeconomy, companies can actively mitigate risks as their supply chain is more resilient. They are less dependent on finite resources, and they are prepared for upcoming regulations in areas such as climate change or waste management. It also enables companies to anticipate shifts in public demand due to abrupt material bans or changes in investors' expectations. For example, with the new Circular Economy Action Plan regulation the EU proposes to reward products based on their sustainability performance and is setting new standards to reduce the carbon and environmental footprint of products.

Customer attraction and retention. Circular bioeconomy business models have the potential to lower the environmental impact of a product and enable constant customer interactions. This potential image shift and new engagement model can significantly support companies in attracting new and retaining existing customers. In a recent survey, 73% of global consumers stated that they would alter their buying habits for environmental purposes.[13]

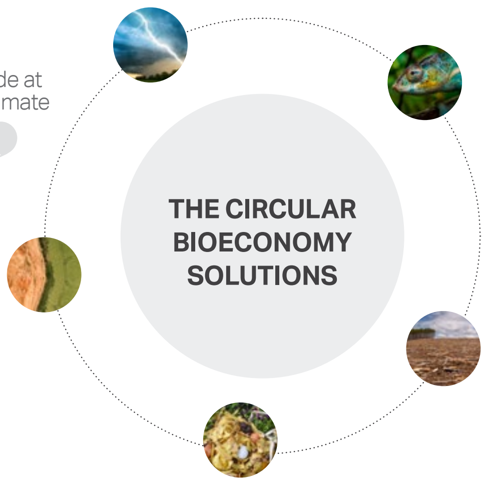
Employee attraction and retention. Through a transformation toward business models that are based on principles of a circular bioeconomy, companies are following a unique purpose with the ambition of improving the current economic systems. Employees actively respond to this vision; they are more likely to join a company with a higher meaning, as well as more motivated and willing to stay longer. Employees that derive meaning and purpose from their work and are inspired by company leadership are 2.25 times more productive, and purpose-oriented companies enjoy 40% higher levels of retention.[14]

Social balancing. The renewable resources feeding into the circular bioeconomy can help with social balancing of industrial centers and rural areas. Many renewable resources such as agricultural and forestry products are grown rurally, bringing jobs, social security, and opportunity for development to these areas outside of urban and industrial centers.

Environmental performance. Finally, circular bioeconomy business models offer a solution to some of our greatest sustainability challenges, as illustrated in Figure 3 and outlined below:

- **Climate change** is mitigated as carbon emissions are reduced through the substitution of fossil-based materials and the introduction of efficient circular production processes
- **Biodiversity** is protected through sustainable farming and forestry practices
- **Land-use change** is reduced through the improved utilization of existing resources, such as secondary biomass, and the sustainable sourcing of new resources
- **Food waste and loss** is reduced through its utilization as production input or through composting
- **Resource scarcity** is mitigated through the continuous cycling of existing resources in closed loops

Figure 3: Role of bio-based materials in shaping the future of production across industries



Climate change
We know that harnessing the power of natural climate solutions to improve decisions related to land use can provide at least 30% of what is needed to keep climate change under 2º C.
The Nature Conservancy

Biodiversity loss
Without drastic action to conserve habitats, the rate of species extinction — already tens to hundreds of times higher than the average across the past ten million years — will only increase.
Nature

Resource scarcity
Global resource use has more than tripled since 1970, and global material productivity has not improved in the last 20 years.
UN IRP

Land use change
Land degradation negatively impacts 3.2 billion people, and represents an economic loss in the order of 10% of annual global gross product.
IPBES

Food loss & waste
Each year, one-third of all food produced in the world for human consumption never reached the consumer's table.
FAO

② Circular bioeconomy as a basis for a sustainable economy

2 Circular bioeconomy as a basis for a sustainable economy

A circular bioeconomy tackles two of the major societal questions our generation is facing: what type of resources we are using, and how are we (re)using them across multiple lifetimes.

A sustainable, low-carbon circular bioeconomy describes the sustainable production and maximum value capture of (secondary) biological renewable resources.
It supports a shift toward a circular, low-carbon economy that counterbalances global warming and meets society's current and future needs for food, products, and energy within planetary boundaries by complementing or substituting existing non-renewable materials.

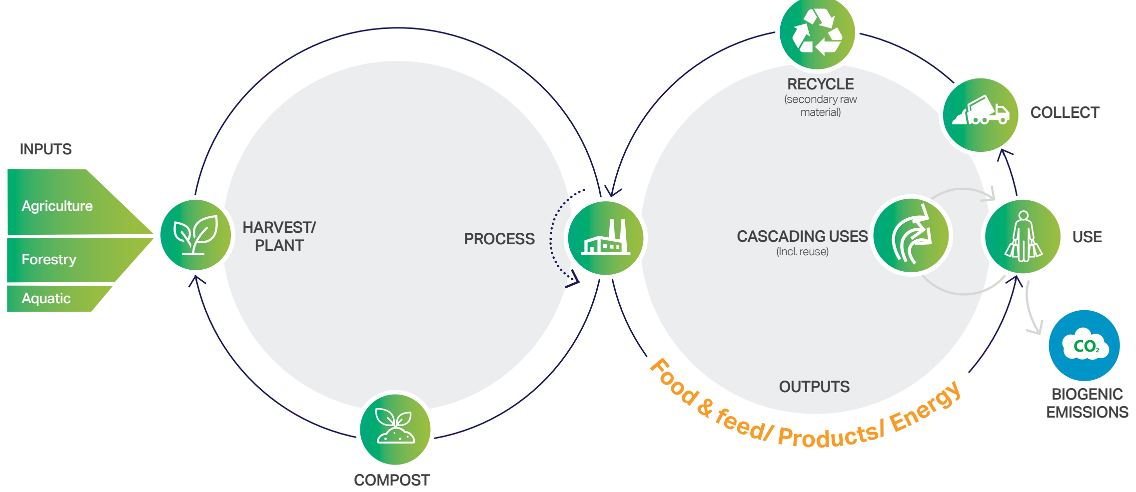
In the following subchapter, the different possible resource loops within a circular bioeconomy are outlined. The second subchapter provides an overview of existing material flows from the biomass source toward possible end uses.

2.1 A CIRCULAR SYSTEM OF BIORESOURCES AND THE PRODUCTION CYCLE OF PRODUCTS, FOOD AND FEED, AND ENERGY

Figure 4 visualizes the flow within the circular bioeconomy. Resources are initially harvested and processed into products, food and feed, or energy, then reused and cascaded over multiple periods, to ultimately be recycled or composted to give the nutrients back to the soil.

The cascading use of materials maximizes resource effectiveness by using biomass in products that create the most economic value over multiple lifetimes. This means that preference for biomass use should be given to higher-value applications and continuous reuse. Energy recovery should be the last option.

Figure 4: Flows within the circular bioeconomy



Nutrient cycle: Materials are harvested and processed into products, food and feed, or energy; composted materials feed nutrients back into the cycle.

Product cycle: Products are cascaded multiple times during their use phase and at the end of their lifetime collected to be recycled/recovered or composted.

Waste: One of the key principles of a circular economy is to design waste out of the system. This is crucial in the circular bioeconomy, as new resources can only be replenished sustainably in limited amounts. Nevertheless, certain waste streams might occur at different stages of the life cycle. During production and processing, waste can include raw material leftovers, rotten biological materials, or emissions from energy consumption.
During the use phase, solid materials (such as food leftovers), emissions from energy consumption, or utilized products without a recycling option can become waste. These waste streams include mixed waste streams that are challenging to recycle efficiently, especially if they have non-organic components. The aim of a circular bioeconomy is to keep these waste streams to a minimum and to feed them back into the input side of the cycle wherever they cannot be eliminated completely. In such cases, the biomass fed back into the cycle is often referred to as secondary biomass or secondary bio-based inputs.

End of life: At the end of its useful life cycle, a product within the circular bioeconomy has two possible loops to follow: either it is collected and the materials are recycled/recovered to remain within the product cycle, or the materials feed back into the nutrient cycle through biodegradation or composting. The ability to return nutrients via biodegradation or composting is a key advantage of the circular bioeconomy relying on renewable inputs. Whether products should be designed to biodegrade or (industrially) compost depends on the expected path at the end of usable product life. In the technical cycle, the main path to return raw materials once all options to reuse, refurbish, and repair have been exhausted is through recycling.

As illustrated in Figure 4, biogenic emissions can be released during the product cycle from the combustion of biomass. Biogenic emissions are emissions that come from natural, non fossil-based sources. These biogenic emissions emit carbon dioxide which has previously already been part of the carbon cycle - for example, stored in trees - while GHG emitted from burning fossil fuels is non-biogenic CO_2, increasing the total amount of carbon in the biosphere-atmosphere system.[15] Given their different nature, according to the GHG protocol, biogenic emissions are not part of Scope 1, 2, or 3 emissions, but corporations are to report on biogenic carbon emissions in a separate memo item. Other emissions (such as CH4 or N2O) from the combustion of biomass should, however, still be accounted for.[16]

Within the first described loop, mechanical as well as chemical recycling are viable options. For example, a plastic bag made from bio-based material could be recycled mechanically for multiple periods or brought back to its base materials via chemical recycling.

For the second loop, materials are biodegraded until they can be used as nutrients for new resources, which can then be harvested and used for the product cycle again. All three biomass sources—agriculture, aquaculture, and forestry—can be used for all three end uses—product, food and feed, and energy—and feedback vice versa. For details on the processing flows, see Chapter 2.2.

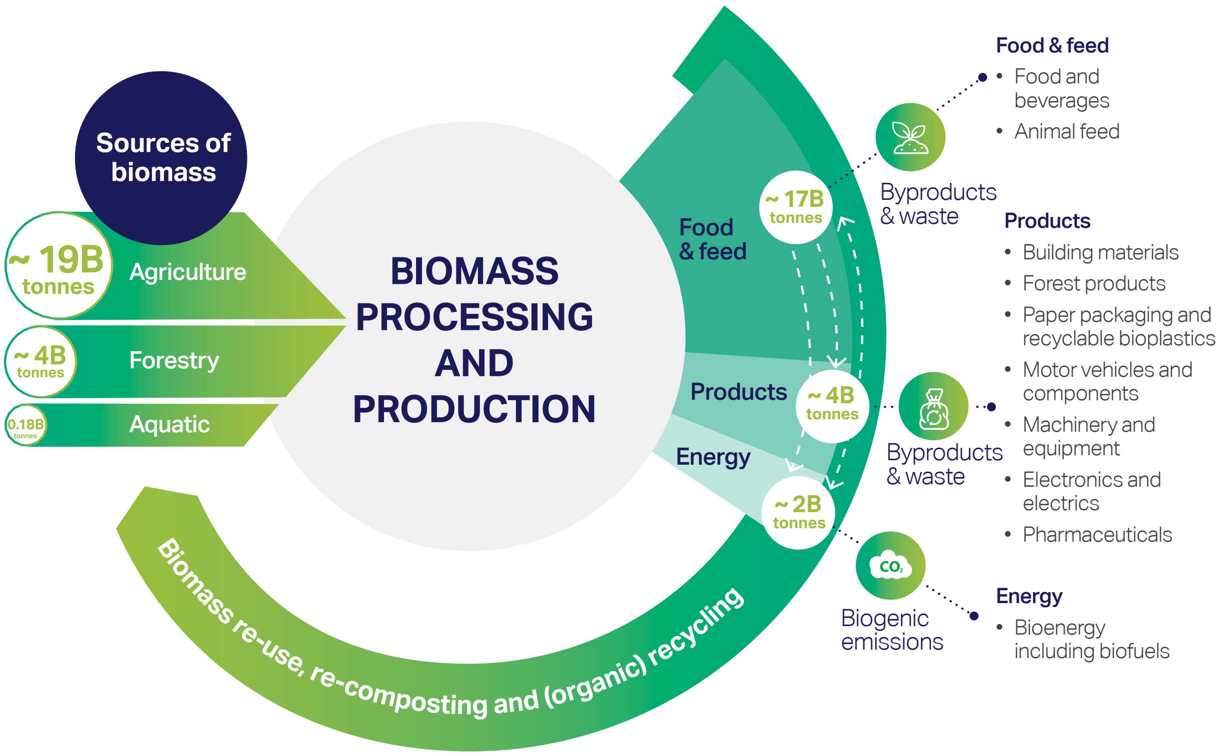
Altogether, in a circular bioeconomy the total, non-renewable, virgin resources fed into the cycle are minimized as most of the resources are either cycled in the product cycle or used as nutrients to plant and harvest new raw materials. In balancing these cycles, overall resource efficiency per usable product is crucial to ensure the use of renewable materials occurs at a sustainable rate. In an optimal scenario, the circular flow is infinite and mimics the natural circle of life.

Upcycling is the recycling of products in such a way as to create a new product with superior value. For example, old truck tarpaulins repurposed into fashion bags or used wooden pallets into furniture. On the other hand, recycling that creates products with inferior value is called downcycling. An example is the waste from products or food and feed that is utilized for biofuel production.

2.2 A VARIETY OF BIOMASS MATERIAL AND PRODUCTION FLOWS

In 2018, 23.1 billion tonnes of biomass went into the processing and production of bio-based products. The main source of biomass was agriculture with 19 billion tonnes, followed by forestry with 4 billion tonnes, and lastly, aquaculture with 0.2 billion tonnes. (See Figure 5.) More than 100 different material flows connect the three biomass sources with the end uses as bio-based products, food and feed, and energy.[17]

Figure 5: Biomass flows from three primary sources into end-uses



Source: Eurostat; Freedonia; OECD; WU Vienna; WBCSD; BCG analysis; Member companies.

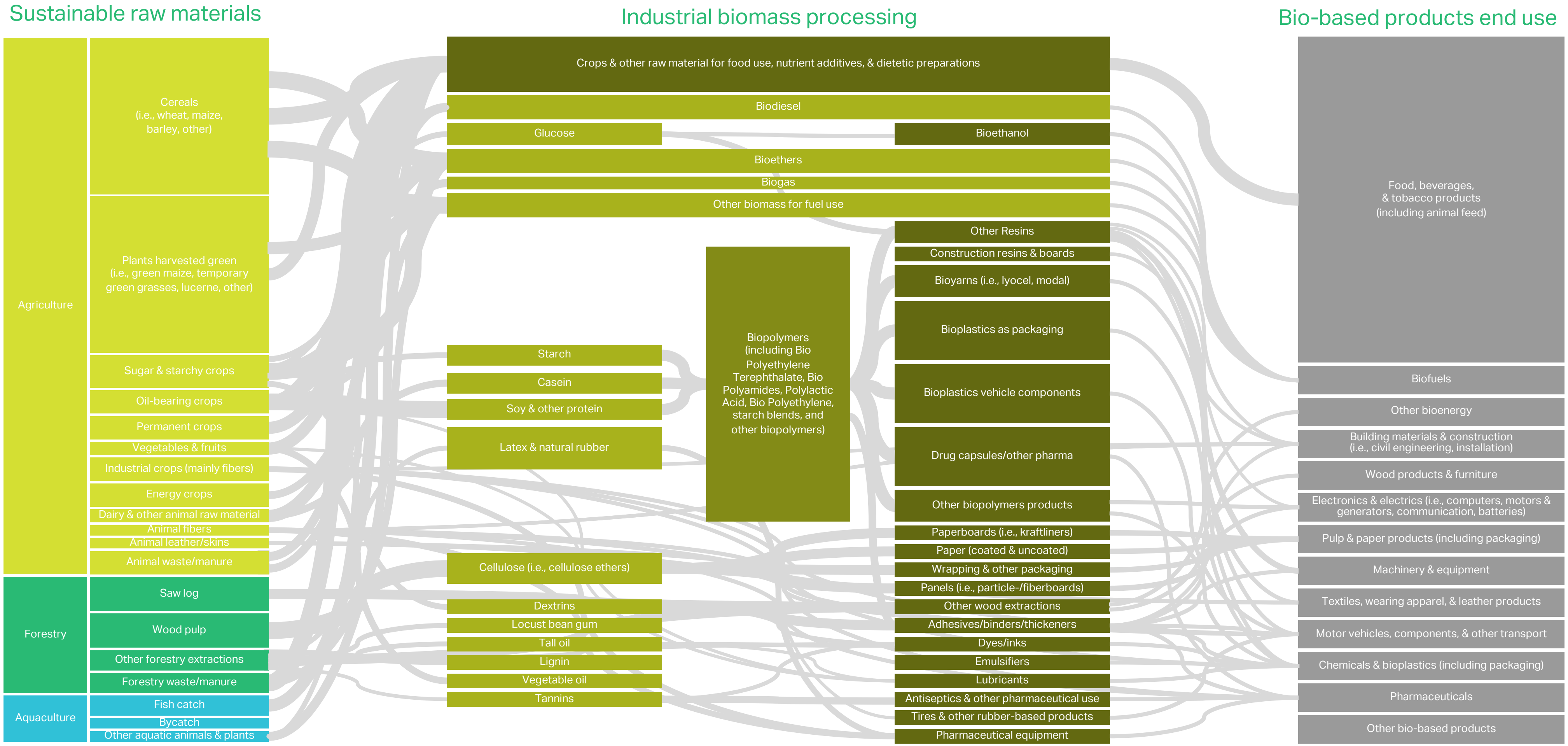
Sourcing and harvesting of biomass: The two main agricultural raw material groups are cereals—for example, wheat, maize, or barley—making up around 28% of the biomass, and plants harvested green—for example, green maize, temporary green grasses, or Lucerne—making up another 28%. A complete overview of the raw material groups can be found in Figure 6.

Raw materials from forestry mainly consist of saw log and wood pulp, followed by other forestry extractions and forestry residues. For aquaculture, the main material groups are fish catch, by-catch, and other aquatic animals and plants.

Processing and end use of biomass: The majority of biomass is processed into food and feed products, equaling around 17 billion tonnes. The smallest portion of the biomass, around 2 billion tonnes, is used for biofuel production. As Figure 6 shows, there is a huge variety of raw material flows and processing steps that connect the biomass sources with the respective end uses. Biomass leaving the circle as waste at any point can be returned to the beginning of the cycle as secondary input. This connection was not explicitly included in the figure but can potentially occur with any biomass.

One major processing category is bioplastics, which can consist either fully or partially of renewable carbon. Within this category, different kinds of bio-based material can be used—for example, the plastic can contain mixtures of synthetic and natural polymers like starch or derivatives of naturally occurring polymers like cellulose. Additionally, synthetic polymers produced from bio-based building blocks are included. The bio-based building blocks used for the production of bioplastics are made from a broad variety of naturally occurring chemical substances such as sugars, which are produced from starchy crops or cellulosic wood, casein from dairy, or oils from oil-bearing crops. Produced bioplastics find a variety of applications, ranging from bio-yarns for the textile industry to technical polymers for vehicle components, packaging materials, or drug capsules. Refer to the industry chapters within Chapter 4 for application examples.

Figure 6: Variety of biomass materials and production flows



3 The business case for a circular bioeconomy

3 The business case for a circular bioeconomy

3.1 SIGNIFICANT GROWTH UNTIL 2030 FOR BIO-BASED PRODUCTS (INCLUDING FOOD)

The total market for bio-based food and feed, products, and energy is expected to grow from USD $10.3 trillion in 2018 to USD $12.8 trillion in 2030, representing a 1.8% annual growth over this time. The required biomass to fuel this growth is expected to increase from 23.4 billion tonnes in 2018 to 26.7 billion tonnes in 2030. (See Figure 7.)

When evaluating the substitutional and complementation potential of a circular bioeconomy, food and feed play a different role compared to bio-based products and energy as they generally do not replace any nonbiological goods.

The industry segment of food and feed can be categorized into two sub-segments:

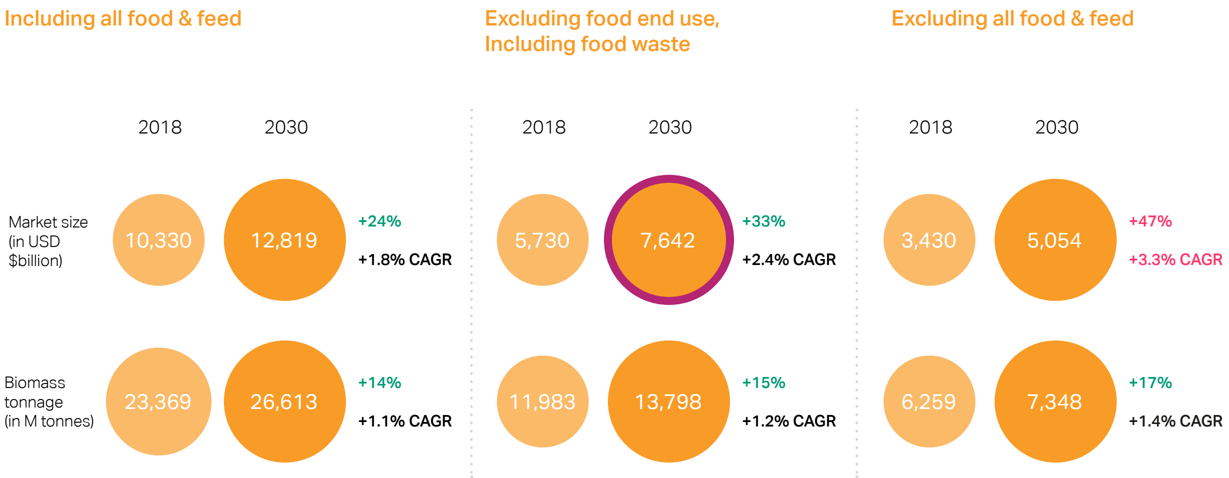
- Food and feed consumption/end use
- Food and feed waste

When evaluating the substitution and complementation opportunity of a circular bioeconomy, we assess the potential in three ways: including the whole food and feed industry, including only the food and feed waste, and excluding the whole food and feed industry segment. (See Figure 7).

Bio-based products and energy, excluding food and feed consumption, is expected to grow stronger compared to the total market – 2.4% per year until 2030, reaching USD $7.7 trillion in 2030. The highest increase is expected in the market segment of bio-based products and energy alone, excluding food and feed consumption as well as waste. Although this segment is comparably small – only making up $3.4 trillion in 2030 – it is expected to grow by 3.3% per year until 2030 and will reach $5 trillion in 2030. Hence, the substitutional and complementation potential for the circular bioeconomy is largest within this market segment of bio-based products and energy.

Across the three market segments analyzed above, the required biomass is expected to grow similarly, with increases of 1.1% to 1.4% per annum until 2030.[18]

Figure 7: Circular bioeconomy growth opportunity until 2030



Note: The second set excludes food but includes food waste
Source: European Commission; Oxford Economics; BCG analysis

The business opportunity is based on the estimated continuous growth rate prior to COVID-19 of bio-based resources used within the respective industries, including the expected substitutional and complementation potential. It includes the value of both virgin and secondary bio-based materials with the opportunity to be cycled in closed resource loops. As this is a wide focus included in the business opportunity in this publication, the size of the overall business opportunity is anticipated to be higher than in studies focusing on direct revenues from circular business models alone.

3.2 A MULTITRILLION GROWTH OPPORTUNITY ACROSS INDUSTRIES

The USD $7.7 trillion business opportunity of bio-based products, energy, and food waste is based on the potential of ten main industries:
Food and feed waste is the largest category, estimated to reach USD $2.6 trillion in 2030. Amongst bio-based products, pharmaceuticals are expected to have the highest potential with USD $750 billion in 2030, followed by textile and wearing apparel as well as building material and construction with USD $700 billion each.

Packaging and motor vehicles and components follow with a USD $550 billion opportunity, respectively. Additional opportunities – ranging from USD $100 billion to USD $200 billion each – are seen in other forest products,[19] electronics and electrical products, machinery and equipment, as well as biomass energy and biofuels. (See Figure 8.)

Details on these opportunities and examples for each industry are provided in Chapter 4.

The chemical industry is a crucial enabler for the circular bioeconomy across all industries and is incorporated in the other industry groupings.

Role of the chemical industry

As bio-based chemicals are often vital precursors for many industries, the chemical industry takes a crucial enabling role in the circular bioeconomy. Two chain of custody models are applied: In segregated value chains, a biobased feedstock is used in a specific plant and the product from this production plant contains the carbon atoms from the renewable feedstock. In the mass balance approach, the renewable feedstock is introduced into the chemical production "Verbund" and allocated to the various end products.

Examples of the use of renewable raw materials in the chemical industry and its enabling role for the other industries can be found across the industry chapters of this report and on the WBCSD website. The bio-based plastic additives developed by Clariant and Neste enable the electronics and electrical industry to make their products more sustainable; the additives rely on renewable hydrocarbons from Neste. (See Chapter 4.7.) DSM is using biowaste-based feedstock for the production of high-tech fibers. (See Chapter 4.2.) BASF is using the biomass balance approach to produce a broad range of products for very different industries, as well as developing new bio-based products such as surfactant with advanced properties.

Replacing fossil-based raw materials with bio-based raw materials aids in closing the loop in the chemical industry, as regaining the required basic molecules for chemicals from recycling the complex finished products is often difficult and energy-intensive. Renewable materials can employ the nutrient cycle, hence enabling a closing of the loop. (See Chapter 2.1.)

Figure 8: Circular bioeconomy growth opportunity until 2030

Market size (in $billion)		Total	Products				
		Total circular bioeconomy (excl. consumed food and feed)	Pharmaceuticals	Textiles & wearing apparel	Building materials & construction	Packaging	Motor vehicles & component
Current	2018	5,750	250	400	350	400	250
			+9.2% p.a.	+4.1% p.a.	+6.2% p.a.	+3.2% p.a.	+6.2% p.a.
Substitutional potential	2030	7,650	750	700	700	550	550
Examples			Vaccines from medicinal plants & herbs Cancer treatment synthesized from plant substances Blockchain technology to produce protein-based medication	High-tech fibers made from biomass or biowaste Plant-tanning agents Compostable textiles Compostable lyocell, modal	Circular wooden structures Composites reinforced with natural fibers Circular bio-based insulation materials	Recyclable flexible packaging paper & paper board Paper packaging replacing plastics (e.g., Liquid Packaging Board for beverages) Recyclable bioplastics Biodegradable starch blends and biodegradable plastic	Natural fibers for body parts Compostable interior lining based on bioplastics Tires based on dandelion in closed loop system

Market size (in $billion)		Products				
		Other forest products	Electronics & electrical products	Machinery & equipment	Bioenergy & biofuels	Food & Feed waste
Current	2018	150	100	50	150	2,300
		+3.5% p.a.	+5.1% p.a.	+5.3% p.a.	+2.3% p.a.	+1% p.a.
Substitutional potential	2030	200	200	100	200	2,600
Examples		Biolubricants Enzyme-based additives	Recyclable bioplastics Polymers reinforced by natural fibers Bio-based casings Lignin for recyclable battery parts	Bioprocess engineering Agricultural engineering	Solid bioenergy including wood pellets (from byproducts) Liquid biofuels incl. biodiesel, biomethane, cellulosic ethanol, renewable "drop-in" fuels	Food & feed waste repurposing Organic nutrient upcycling Bioenergy, biofuels, and chemicals out of food waste

Source: European Commission; Oxford Economics; WBCSD; BCG analysis, Member companies; Based on rough estimations and rounded market sizes, sorted by substitutional potential in 2030

④ Significant opportunities and high growth rates across industries

4 Significant opportunities and high growth rates across industries

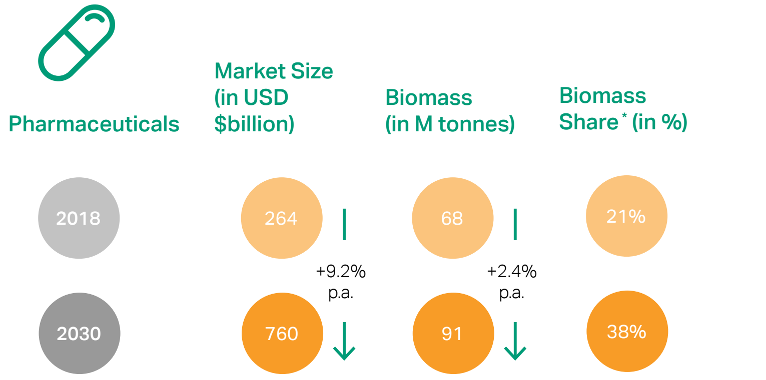
This chapter provides an overview of the relevant industries within the circular bioeconomy and case examples of companies successfully implementing pertinent strategies.

To begin, relevant bioeconomy product industries are discussed in decreasing order by expected potential in 2030. Next, details of the biomass energy and biofuels industry are elaborated upon, followed by an examination of the food and feed waste industry. For this industry, we focus specifically on the composting of food and feed waste; the discussion of upcycling and energy opportunities can be found in prior chapters.

Many end consumers have a strong demand for "naturalness" regarding products they take into their bodies like pharmaceuticals and nutrients, or that get into contact with their body like cosmetics and shampoo. This demand presents a high growth potential in the health and care industry for bioeconomy products like biopharma as well as bio-based cosmetics or surfactants. The latter are not included in the scope of pharmaceuticals in this chapter.

4.1 THE BIOECONOMY IN PHARMACEUTICALS[20]

Figure 9: Growth opportunity in the pharmaceutical industry



*On overall material use in industry
Source: European Commission; Oxford Economics; WBCSD; BCG analysis, Member companies

- Total market size is estimated at USD $264 billion
- 21% of material used in the industry is estimated to be biomass, equaling 68 million tonnes of biomass
- Market value is estimated to grow by 9.2% per annum and the biomass by 2% per annum until 2030, clearly showing that the relative value is superior

SPECIFIC INDUSTRY CONDITIONS AND ENABLERS

Biopharma refers to pharmaceuticals that are manufactured from biological processes. Existing synthesized medication faces various challenges that biopharma can profit from, such as it is not always tolerated by patients, has more side effects in specific cases, and can be more expensive in production. Biopharma is therefore playing an increasingly important role in accessibility—for example, biopharma makes it possible to supply insulin for the number of patients who need it.

BIOECONOMY INDUSTRY TRENDS

Innovative bio-based pharmaceuticals
Biopharmaceuticals are large biological molecules, such as proteins, used to treat diseases that cannot easily be addressed by chemical molecules, such as autoimmune diseases or cancer. Currently, the introduction of blockchain into the production of biopharma is increasingly being discussed.

Plant-made pharmaceuticals
In recent years, pharmaceutical research has found new innovative agents based on biomass, such as an HIV vaccine from tobacco plants, or carrot cells to treat certain metabolic disorders. Chamomile, flax, lady's thistle, peppermint, and buckthorn together represent the largest share of plants used for pharmaceuticals; 75% of medicinal plants are used for phytopharmaceuticals and the remainder are used for health food (18%) and cosmetics (7%).

Semisynthetic pharmaceuticals
In order to meet demand for biopharmaceuticals, especially for agents with limited natural availability, certain pharmaceuticals are produced through semi synthesis with chemicals.

BASF: BIOTECHNOLOGICAL PRODUCTION OF RIBOFLAVIN (VITAMIN B2)

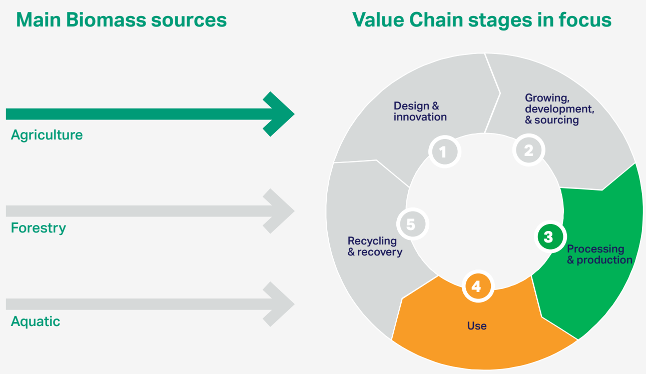
Vitamin B2 is an essential micronutrient for humans and animals. The global world market for vitamin B2 more than doubled from 4000 tonnes in 2002 to 9000 tonnes in 2015. Vitamin B2 is an example of a complete shift from chemical synthesis to exclusive biotechnological production in less than 15 years.

For almost five decades, commercial vitamin B2 was produced almost exclusively by chemical synthesis. The main disadvantages were the low yield of about 60%, as well as the use of toxic agents such as amalgam and xylidine and thereby the production of waste products that required environmental control and special effluent treatment. For these reasons, first attempts to obtain vitamin B2 by fermentation had already started in 1940. By using a fungus-based system, BASF achieved the industrial-scale fermentation of vitamin B2 in 1990, starting from vegetable oil as the main carbon source.

A comprehensive eco-efficiency analysis conducted by BASF in 2003 determined that the fermentative process is more sustainable than the chemical route. Besides the environmental advantage of a 30% decrease in CO_2 emissions and a reduction of hazardous substances, a significant economic advantage was shown, with a 40% reduction in production costs.

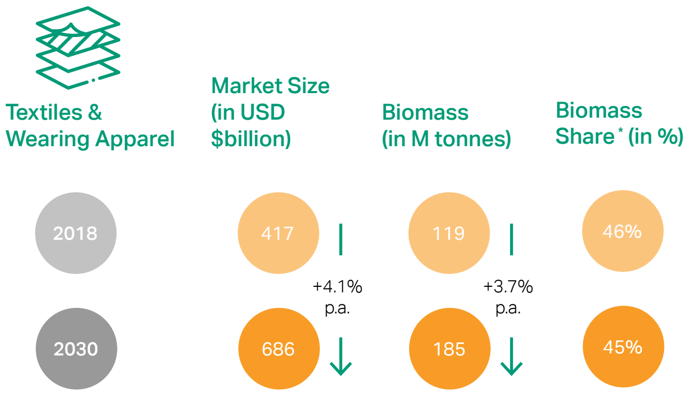
Today, 100% of vitamin B2 on the global market is produced by fermentation using biotechnology.

Figure 10: Main biomass sources and value chain stages in focus



4.2 THE BIOECONOMY IN TEXTILES & WEARING APPAREL[21]

Figure 11: Growth opportunity in the textiles & wearing apparel



* On overall material use in industry
Source: European Commission; Oxford Economics; WBCSD; BCG analysis, Member companies

- Total market size is estimated at USD $417 billion
- 46% of material used in the industry is estimated to be biomass, equaling 119 million tonnes of biomass
- Market value is estimated to grow by 4.1% per annum and the biomass by 3.7% per annum until 2030, showing that the relative value stays similar

SPECIFIC INDUSTRY CONDITIONS AND ENABLERS

There is an increasing demand for textiles and wearing apparel due to a growing world population expected to reach 10 billion people by 2050. Circular, bio-based textiles can help reduce the 60 million tonnes of textiles that are thrown away every year – a number that equals about a quarter of all textiles produced per year.

Over 50% of textile fabrics are currently fossil-based, yet these materials are experiencing public scrutiny. Based on a recent survey, 84% of consumers are open to sustainable fashion, and 71% would even pay more for it.[22] This presents a valuable opportunity for circular, bio-based materials as a sustainable alternative to fossil ones. Man-made cellulosic fibers (MMCF) can tap into this opportunity twofold, as they are often more resource- and cost-efficient in combination with satisfying the consumer's desire for sustainable alternatives.

BIOECONOMY INDUSTRY TRENDS

Traditional natural fibers
Natural fibers make up an approximate 41% share in the textiles market, behind synthetic fibers (59%). The largest share among natural fibers comes from cotton (61%), with the rest being shared by other plant-based fibers (34%) and animal-based fibers such as wool and silk (less than 5%).[23] One of the major disadvantages of the largest conventional natural fiber, cotton, is its high water and chemical consumption in the production process. Man-made cellulosic fibers address this issue (see below for details) and in recent years, technologies have been developed to recycle cotton into viscose fibers. The introduction of multiple use cycles through recycling reduces the impact of initial water and chemical consumption.

Innovative natural and synthetic bio-based fibers
New natural fibers include jute, flax, and hemp, which primarily serve as technical textiles for industrial use. Unlike cotton fibers, natural and chemically produced viscose fibers are characterized by greater variation in their fiber geometry, and as a result, they have more extensive application.

In recent years, replacements for traditional animal-based fibers have been developed. Synthetic spider silk relies on the same proteins as natural silk but is created via fermentation spun into yarns. Similarly, protein-based replacements for fur, leather, and wool are being developed.

Man-made cellulosic fibers (MMCF)
Among natural fibers, man-made cellulosic fibers such as viscose, modal, and lyocell have some of the highest growth rates (CAGR of about 7% to 15%) with an expected revenue of USD $20 billion in 2030. These are made from cellulose found in eucalyptus or beech wood, for example. Prominent drivers for this development are the growing acceptance of viscose and lyocell fibers, growing preference toward biodegradable fabrics, and increased acceptance of viscose and lyocell-based home textiles.

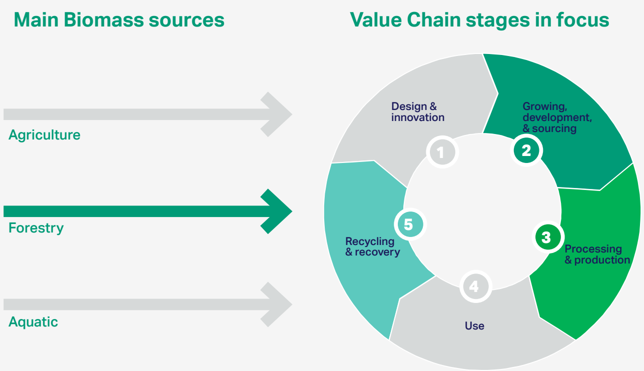
DSM: HIGH-TECH FIBERS FROM BIO-BASED FEEDSTOCK

DSM has introduced bio-based feedstock into the production of Dyneema®, the world's strongest fiber. Dyneema® invites multiple uses, from ropes and lines to lightweight high-performance fabrics for outdoor and sports use, such as cycling jerseys, tents, and backpacks. Due to their extreme robustness, garments made with Dyneema® last longer than comparable traditional products, lengthening the cycle lifetime. By introducing bio-based feedstock, the use of fossil-based resources can be reduced. For every metric ton of bio-based Dyneema® that is produced, DSM is saving approximately 5 metric tonnes of CO2 equivalent compared to fossil-based Dyneema®.

DSM aims at least 60% of the Dyneema® fiber feedstock to be bio-based by 2030.

In addition, DSM Protective Materials has established an industry coalition consisting of customers, waste processors, and recycling companies to address the recycling of products made with Dyneema® fiber at the end of their use. An end-of-life program has been set up with a goal for the materials to be cycled in a closed loop through continuous use and recovery.

Figure 12: Main biomass sources and value chain stages in focus



BIRLA CELLULOSE: RESPONSIBLY PRODUCED VISCOSE, MODAL, AND LYOCELL FOR SUSTAINABLE FASHION

Birla Cellulose as part of Aditya Birla Group is deriving viscose, modal, and lyocell fibers from wood sourced from sustainably managed forests and produced by closed loop processes. In doing so, they achieve six key impacts:

First, a drastic reduction in water use, as water required for viscose production is about 1% of the equivalent cotton water consumption.

Second, a drastic reduction of pesticide and fertilizer use in comparison to the growth of cotton.

Third, the ability to recycle between 90% to 99.7% of solvents used in the manufacturing of Livaeco viscose fibers and Excel lyocell fibers.

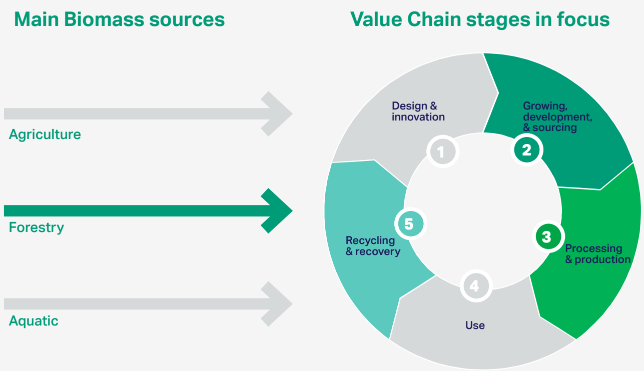
Fourth, carbon neutral operations, as the forests directly managed by Birla Cellulose sequestered 3.44 Mt CO2e in 2019 as opposed to only 3.22 Mt CO2e emitted through its entire global operations.

Fifth, full biodegradability of viscose, modal, and lyocell in four to six weeks in land, water, and marine conditions, while synthetic fibers stay in the environment for hundreds of years, creating land and water pollution.

Sixth, the use of recycled cellulosic waste in the production of innovative Liva Reviva viscose fibers, in combination with wood-based pulp. This partial reuse reduces fresh raw material needs, which is a crucial aspect for the circular bioeconomy.

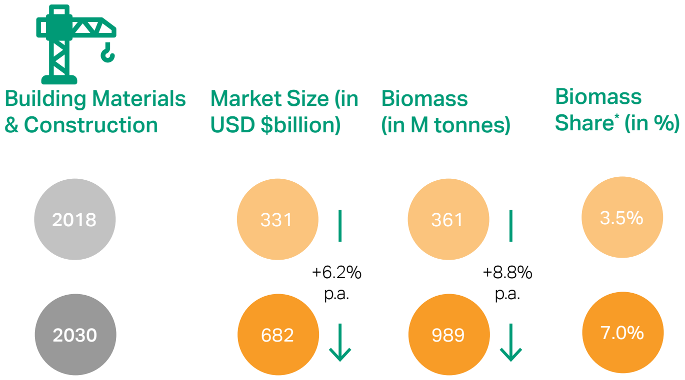
Through this comprehensive strategy, Birla Cellulose was ranked number one in Canopy's Hot Button Report that ranks viscose producers based on sustainable wood sourcing and forestry practices—a strong competitive advantage when satisfying the growing market for sustainability-aware fashion.

Figure 13: Main biomass sources and value chain stages in focus



4.3 THE BIOECONOMY IN BUILDING MATERIALS & CONSTRUCTION[24]

Figure 14: Growth opportunity in the building materials & construction industry



*On overall material use in industry
Source: European Commission; Oxford Economics; WBCSD; BCG analysis, Member companies

- Total market size is estimated at USD $331 billion
- Only 3.5% of material used in the industry is estimated to be biomass, equaling 361 million tonnes of biomass
- Market value is estimated to grow by 6.2% per annum and the biomass by 8.8% per annum until 2030, showing that the relative value is slightly inferior

SPECIFIC INDUSTRY CONDITIONS AND ENABLERS

Buildings are emitting 39% of energy-related carbon emissions globally, with a breakdown of 28% from operational emissions (including heating, cooling, and powering the buildings) and the remaining 11% from materials and construction of buildings. In addition, as the world's population approaches 10 billion toward 2050, the global building stock is expected to double in size. Thus, the construction sector has a high and increasing carbon footprint,[25] making the sector one of the largest contributors to climate change.[26]

With a global material use of 84.4 billion tonnes in 2015,[27] the building and construction industry is a major consumer of non-renewable resources such as stone, sand, and minerals. The resulting waste streams account for 25% to 30% of European waste,[28] illustrating the opportunity that the circular bioeconomy provides for the industry to create innovative, decarbonized, and overall sustainable solutions.

Wood as a building material, for example, has the advantage of continuing to store the carbon sequestered during tree growth until it is burned or composted. Therefore, it is able to significantly contribute to a lower carbon footprint of buildings and is increasingly gaining attention within the industry. (See Bioeconomy Industry Trends below.)

The recognition of healthy working and living environments is steadily growing, and material choice is increasingly affected by this awareness.[29] Many renewable materials hold the potential to fulfill this demand, creating a strong opportunity for the circular bioeconomy.

BIOECONOMY INDUSTRY TRENDS

Increasingly integrate wood-/ bio-bbased products in structural elements of buildings
Bio-based construction materials such as wood are increasingly replacing conventional building materials. In 2017, over 60% of all bio-building materials came from forestry. Modern wood products, such as laminated veneer lumber (LVL) or cross laminated timber (CLT) can be used to create load-bearing walls from large sheets and allow offsite premanufacturing to increase construction efficiency when compared to more traditional wood frame construction onsite. Through these new material developments, it is now possible to produce a multi-story building from bio-based materials.

Bio-based interior construction

The use of biomass-based building materials for interior finishing includes, among others, natural fibers and resins for insulation, lining, and floor coverings. Bio-based interior building materials often require less energy in production and through good insulation properties can further reduce building lifetime energy use.

Healthy living conditions are driven by the right use of materials in interior construction. Bio-based materials can contribute to this if kept free from harmful additives.

Recent trends, such as biophilic design promoting the connection of interior spaces to the natural environment, heavily rely on bio-based materials.

Wood fibers and lignin in biocomposites

Composite materials can give high strength to complex shapes. In recent years, wood fibers and lignin, a fraction of biomass, have seen increased use in composite materials. Lignin from biomass waste is used as a plasticizer in concrete production, which reduces water use by 15% as compared to conventional chemical plasticizers. Wood-cement composites exhibit good bending and shear stiffness and can make use of recycled pulp and solid wood waste. Polymer-based biocomposites combine bio-based fibers and polymers to form high strength materials. Polymers can be conventional, recycled, or biobased. (See Chapter 5.4.1 for additional details on bioplastics)

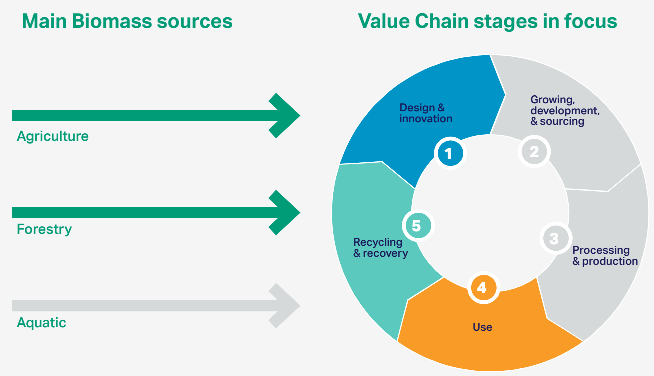
ARCADIS: RESOURCE AND ENERGY EFFICIENT BUILDING STRATEGY USING ORGANIC CONSTRUCTION MATERIALS

Arcadis and MVSA Architects designed the Holland Casino Venlo to reduce energy and resource use, employing several of the principles detailed above.

The design incorporates the previous casino structure, reducing the need to replace what is still usable and hence saving the associated cost and CO2 emissions. The building's skeleton consists of removable and reusable wooden beams and the insulation is made of 100% hemp fiber, keeping the carbon captured during growth in the material. Many of the materials used have residual value, increasing the likelihood of reuse at the building's end-of-life.

In daily operations, rainwater is collected for use in the greywater circuit and later purified by a living sand–reed helophyte filter, reducing the need for external sewage treatment. To reduce energy consumption and cost, photovoltaic film captures solar energy, visitors generate energy through the interactive entrance floor, and light tubes direct daylight into the interior, reducing the need for artificial lighting during daytime.

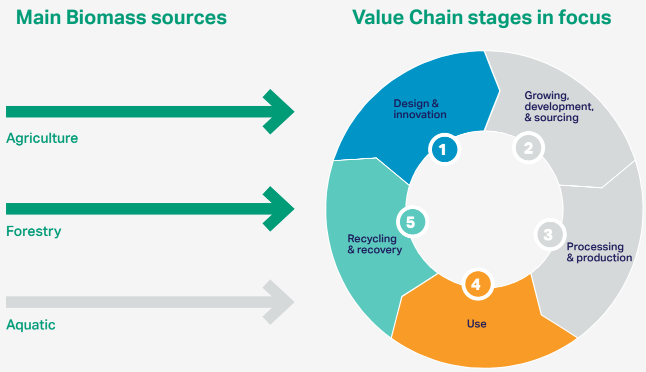
Figure 15: Main biomass sources and value chain stages in focus



NESTE: TURNING SUSTAINABLE WASTES AND RESIDUES INTO A BUSINESS OPPORTUNITY

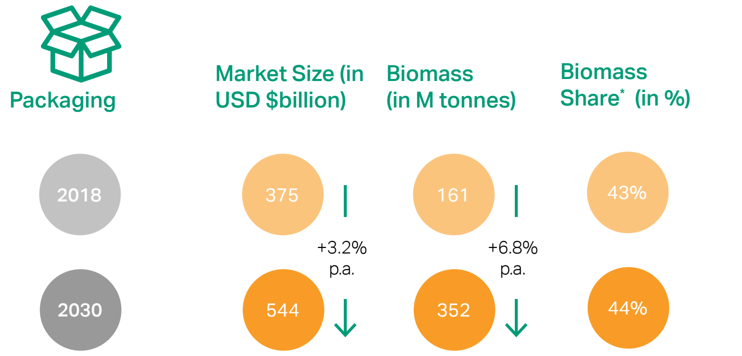
Neste Renewable Polymers and Chemicals is promoting circular bioeconomy by bringing sustainable waste and residue-based feedstock for the chemicals and polymers industry. The feedstock is suitable for use in any typical plastic application including the ones covering building materials and construction. The company currently supplies the market with its bio-based feedstock from its current production facilities while it develops Chemical Recycling technologies and capacity together with several value chain partners. Neste aims to enable reduction of the use of virgin fossil resources in production of polymers and chemicals by offering high-quality, drop-in alternative hydrocarbons based on, for example, bio-based wastes and residues as well as plastic waste. In 2019, Neste used 2.9 Mtonnes of sustainably sourced bio-based feedstocks in its production and the corresponding production of the bio-based fuels and materials helped the users of these products reduce greenhouse gas emissions by 9.6 Mtonnes, equaling the carbon footprint of 1.5 million average EU citizens. From 2030 onwards, Neste's target is to process over 1 million tonnes of plastic waste annually helping to further reduce the use of fossil resources in the production of plastics and chemicals. Key focus is on creating a valuable use for plastic waste that is otherwise destined to landfill or incineration, as it has low or no value in mechanical recycling, due to e.g. challenging material combinations, complex structures, or use of adhesives, inks or additives. Chemical Recycling complements mechanical recycling and accelerates the shift to a circular plastics economy.

Figure 16: Main biomass sources and value chain stages in focus



4.4 THE BIOECONOMY IN PACKAGING[30]

Figure 17: Main biomass sources and value chain stages in focus



*On overall material use in industry
Source: European Commission; Oxford Economics; WBCSD; BCG analysis, Member companies

- Total market size is estimated at USD $375 billion
- 43% of material used in the industry is estimated to be biomass, equaling 161 million tonnes of biomass
- Market value is estimated to grow by 3.2% per annum and the biomass by 6.8% per annum until 2030, showing that the relative value is inferior

SPECIFIC INDUSTRY CONDITIONS AND ENABLERS

One of the main drivers for increased packaging is the rising mass e-commerce sector in which packaging was worth USD $28 billion in 2017, a number expected to double by 2023. Most of this packaging comes from corrugated paper, fibre-based board formats (about 80%), but bioplastics is also gaining importance. Even before the COVID-19 pandemic, e-commerce had been experiencing impressive growth, with a global growth outperforming brick-and-mortar sales by a factor greater than ten, and retail sales online were expected to rise from just 12% in 2017 to 22% of total retail sales (equal to USD $6.5 trillion) by 2023. During the COVID-19 pandemic, e-commerce has increased even further, and a BCG study predicts that online sales as a percentage of the total will continue to grow far faster than pre-pandemic estimates, even after the crisis ends.[31]

Another major driver is the increasing food home delivery market that currently equals 4% of the food produced in restaurants, is expected to increase by 9% until 2023, and has seen a spike as a consequence of the COVID-19 pandemic.

The ongoing public trend away from single-use plastics provides a vast opportunity for bio-based feedstock as input material. This segment is expected to grow by almost 18% per annum until 2021, with a focus on substituting conventional rigid plastic types. Packaging plays a vital role in protecting the encased products and preventing product waste—for example food waste in logistics—hence enabling the saving of resources. Hygienic considerations and potential biological reactions concerning food contact need to be considered to allow for safe packaging options in line with regulations.

Credits: Stora Enso

BIOECONOMY INDUSTRY TRENDS

Flexible packaging paper (fiber-based)

Flexible paper is used for food, tobacco, medical, pharma, cosmetics, and personal care packaging due to its light weight and low production and freight costs; it is among the fastest growing packaging materials with a CAGR of 3.4% until 2022 (compared to a CAGR of 2.9% in the overall packaging industry and a CAGR of 2.8% for paper board).

Board-based packaging (fiber-based)

Three types of packaging board are currently in use: corrugated board (for example for online trade, food & drink, and industrial products), folding cartonnes (for example for food or pharma), and liquid packaging board (mainly for dairy, fruit drinks, and more recently cosmetics); these are overall advantageous compared to plastics due to lower production costs. Paper board represents a large share of about 35% in the global packaging market.

3D formed fiber

3D formed fiber or pulp forming packaging present a promising alternative to fossil fuel-based packaging materials for food, cosmetics, and a wide range of products. Formed fiber can be used for the production of most 3D shapes achieved in plastic today and has the potential to replace more than 90 billion single-use plastic items in Europe alone, a market estimated at USD €2 billion.[32] These wood-based packaging materials are plastic-free, biodegradable, renewable, recyclable, and food and hygiene safe.

Bioplastics in packaging

Only about 1% of all packaging currently covers bioplastics (such as Bio-PET for drinking bottles or Bio-PE for food, cosmetics, and pharma packaging). Nevertheless, this segment is expected to grow rapidly. Bio-based polymers are expected to grow at a CAGR of 18% until 2021. Please see the following deep dive for more detailed information.

5.4.1 DEEP DIVE: BIOPLASTICS AS A FAST-GROWING OPPORTUNITY

Over one-third of all packaging is currently plastics-based, with a growing trend. Unfortunately, only a small portion of around 9% of the material used is being recycled at the moment, as opposed to around 60% for paper and board.[33] To tackle this issue, various fast-moving consumer goods and beverage companies have begun to use recycled post-consumer conventional plastic waste as input material for new plastic packaging and are looking into bioplastics as alternatives.

Bioplastics makes up only around 1% of total packaging but offers a huge untapped business opportunity due to its expected growth of 18% per annum until 2021—by comparison, conventional plastics is expected to grow only 3.6% per annum

Within the plastic packaging segment, we differentiate between rigid and flexible packaging. Bioplastic is mainly used for rigid packaging, making up 1.3 million tonnes, versus flexible packaging with 0.9 million tonnes.

Bioplastic is a term that is used for three different types of plastic:[34]

1. **Bio-based plastics**, meaning plastics that is (partly) derived from biomass (plants). Biomass used for bioplastics stems from corn, sugarcane, or cellulose, to name a few.
2. **Biodegradable plastics**, meaning plastics that can be decomposed by bacteria or other living organisms in a specified amount of time. Biodegradation is a chemical process during which microorganisms that are available in the environment convert materials into natural substances such as water, carbon dioxide, and compost (artificial additives are not needed). Biodegradation does not depend on the resource basis of a material but is rather linked to its chemical structure. Thus, biodegradable plastics can be based on biological or fossil fuel feedstock.
3. **Bio-based plastics** that are biodegradable, meaning plastics that are based on or derived from biological feedstock and can be decomposed in a specified timeframe.

In this report, we define bioplastics as bio-based plastics, or plastics based on biological feedstock. Biodegradability or industrial compostability are strongly desired for certain products, but not at all tolerable for others, depending on the application of the bioplastics.

Rigid bioplastic packaging
Bio-PET is the main type of rigid bioplastics with 870,000 tonnes being used per year, and has the largest expected growth potential of 34% per annum from 2016 to 2021; it is mainly (81%) used for plastic bottles. This type of plastic is followed by Bio-PE with 117,000 tonnes and PLA with 116,000 tonnes. Other bio-based materials that are less widely used are starch-based plastics (63,000 tonnes), PBAT (35,000 tonnes) and PHA (16,000 tonnes).

Flexible bioplastic packaging
Flexible bioplastics is mainly based on starch blends, making up 414,000 tonnes, and followed by Bio-PE with 220,000 tonnes. Less widely used bioplastic materials are PBAT (81,000 tonnes), PLA (77,000 tonnes), PBS (72,000 tonnes), and PHA (39,000 tonnes).[35]

Depending on their composition, polymer-based biocomposites can be classified as bioplastics, too. These composites combine bio-based fibers, such as lignin or cellulose, and polymers to form high strength materials that can be used in packaging but are more frequently used as structural components for electrical equipment or vehicle components. If the employed polymers are bio-based, the resulting composite is entirely bio-based. Conventional composite-plastic materials such as glass fiber- or carbon fiber-reinforced plastics are challenging to recycle as the different materials are difficult to separate and mixed material recycling often yields products with degraded material properties, limiting future applications. Composites entirely relying on biodegradable components solve this issue but are not yet widely spread.

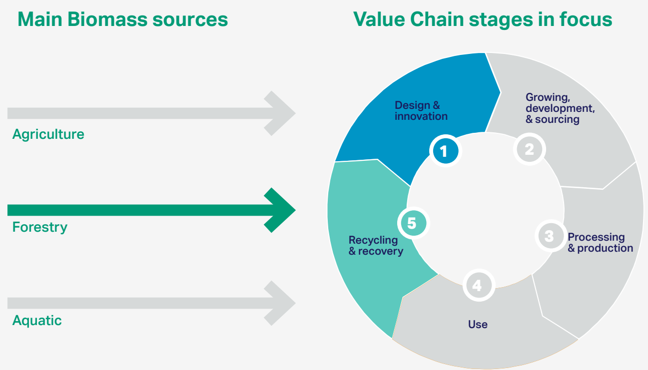
MONDI GROUP: MONO-BIOMATERIAL DESIGN EMPLOYING HIGH PAPER RECYCLING RATES

Mondi partnered with Austrian fruit preserves company Darbo to develop a more sustainable packaging solution. Fruit preserves are delivered to the point of sale in shelf-ready trays of multiple glass jars, traditionally made from a corrugated base and covered with a plastic film. Mondi developed a packaging solution that eliminates the use of plastic. The new packaging is 100% corrugated board, bearing multiple advantages. Being mono-material, the likelihood of incorrect disposal is reduced. Focusing on cardboard, the solution taps into the high 60% global recycling rate for paper products.[36] The packaging itself is also made from 65% recycled content and 35% fresh fiber.

In practical terms, the packaging is easier to open than the previous design, saving time at the point of sale, yet it uses the existing production processes.

The sturdy design is more durable in transportation, reducing food waste due to damages during transport.

Figure 18: Main biomass sources and value chain stages in focus



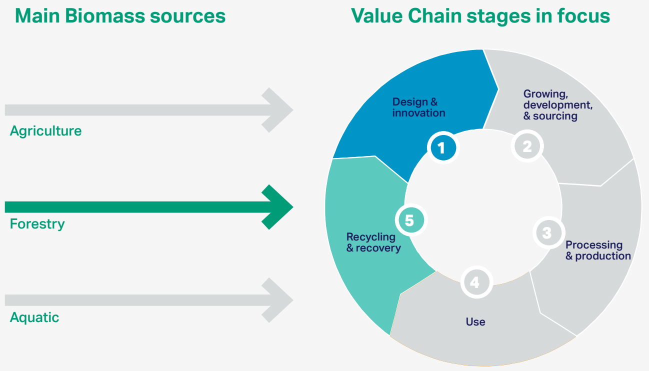
INTERNATIONAL PAPER: CORRUGATED ALTERNATIVE TO RETURNABLE PLASTIC CONTAINERS

International Paper developed a custom corrugated alternative to replace Returnable Plastic Container (RPC) trays for the transport of packaged raw protein.

The materials used are renewable, recyclable, and compostable. The corrugated packaging does not need to be returned to be washed, eliminating food safety concerns and the considerable resource consumption in RPC logistics. This effect is amplified by the reduced weight and 70% lower freight space requirements of the corrugated alternative. For every trailer of corrugated trays unloaded, producers would have to unload 3.5 trucks of RPCs to move an equal amount of packaged raw protein.

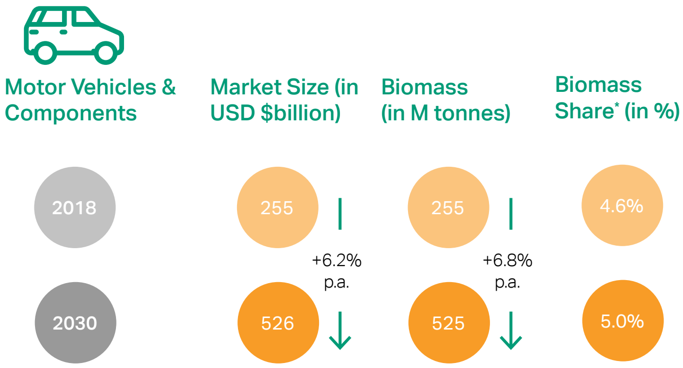
Contrary to initial instincts, this single-use, recyclable solution is more sustainable compared to the prior multi-use solution, mainly due to the use of renewable input materials and reduced losses in logistics. The use of corrugated trays over RPCs results in less transportation, improved ergonomics for packing employees, faster run rates, and ultimately significant cost savings. Freight costs savings of onion growers, for example, are estimated at USD $760,000 annually, while back-hauling RPCs can incur over USD $1 million in costs for shipping, handling, and washing.

Figure 19: Main biomass sources and value chain stages in focus



4.5 THE BIOECONOMY IN MOTOR VEHICLES & COMPONENTS[37]

Figure 20: Growth opportunity in the motor & vehicle components industry



*On overall material use in industry
Source: European Commission; Oxford Economics; WBCSD; BCG analysis, Member companies

- Total market size is estimated at USD $255 billion
- Only 4.6% of material used in the industry is estimated to be biomass, equaling 255 million tonnes of biomass
- Both market value and biomass volume are estimated to grow by 6.2% per annum

SPECIFIC INDUSTRY CONDITIONS AND ENABLERS

The automotive and transportation sector is facing unprecedented disruption linked to environmental and societal challenges: 20% of greenhouse gases are attributed to this industry. Over 50% of the global petroleum is consumed by the transport sector, including fuels, lubricants, and vehicle components. Automotive manufacturing is a highly resource- and energy-intensive process with 15% to 20% of the carbon emissions occurring during the production process.[38] Around 10% of all global plastics is used for motor vehicles. Moreover, the role of automotive in urban mobility systems is changing, for example due to emerging players of digital mobility services. The bioeconomy provides a vast opportunity for the sector to reduce their carbon footprint, respond to requests for stringent emissions and pollution reduction, move away from fossil-based materials, and be part of the growing public and governmental trend toward greener mobility.

BIOECONOMY INDUSTRY TRENDS

Biopolymers for automotive use
Different types of biopolymers such as PLA and PBS are used in motor vehicles to replace conventional plastics and even metal car components, with the advantage of reducing vehicle weight due to innovative lightweight biopolymers and other bio-hybrid materials. The global bio-based polymer market in automotive is expected to grow at a CAGR of 6% until 2025. Please refer to Chapter 4.4 for more information on bioplastics.

Natural fibers in motor vehicles
Various natural fibers are used in innovative automobiles, such as hemp for specific boards and vehicle steel parts, or sisal fiber for floor mats. Currently, around 400,000 tonnes of innovative wood-plastic composites are being produced in the global automotive sector—for instance, researchers are currently analyzing production of carbon fibers from lignin to be used in automotive composite materials.

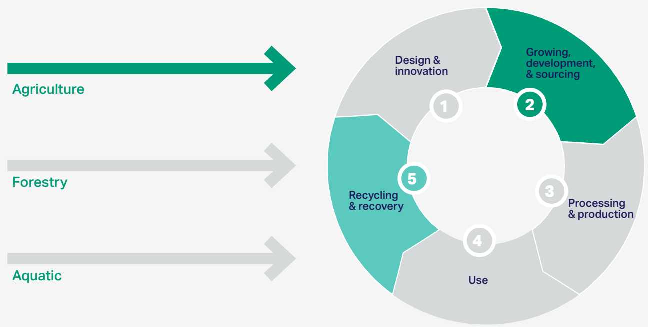
Tires made from dandelion or guayule
While conventional tires for motor vehicles consist of about 30% caoutchouc from rubber trees, newer innovations include the ongoing development of tires made from dandelion or guayule, which provide benefits in terms of land use and transportation. Other circular initiatives in tires include using silica derived from rice husk ash as an alternative source for silica, and the use of alternative oils, as outlined below.

GOODYEAR: REPLACING MINERAL OILS WITH PLANT OILS

Goodyear replaces petroleum-based oils with soybean oils in their tire production. Besides replacing a fossil raw material with a bio-based material, the use of soybean oil also promotes resource efficiency. Goodyear's tests have shown rubber made with soybean oil mixes more easily in the silica-reinforced compounds used in manufacturing certain tires, improving manufacturing efficiency and reducing energy consumption.

As only 65% of the soybean oil produced in the US is used in food applications, a significant surplus is available for valorization. Goodyear's innovation proves that research and development in sustainable materials can benefit not only the environment, but also tire performance. For example, soybean oil helps keep a tire's rubber compound pliable in changing temperatures. This has proven beneficial in the production of all-weather tires, helping to make this important business segment more accessible. This highlights the value of continued research and use of this innovative technology going forward. Goodyear aims to replace all petroleum derived oils by 2040.

Figure 21: Main biomass sources and value chain stages in focus

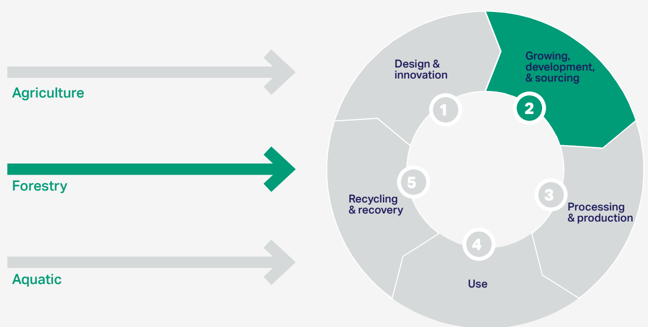


STORA ENSO: FROM TREE TO BATTERY

Stora Enso is developing a technology that uses dry lignin from wood to manufacture a graphite replacement material for the needs of consumer electronics and the automotive industry, among others. Using biocarbon from wood as an alternative to fossil carbon sources not only helps to substitute fossil-based materials with renewables, but also enables carbon capture from the atmosphere, helping to create a low net-carbon emission economy. To satisfy the soaring demand from e-mobility and electronics, Stora Enso is investing in their Sunila Mill plant, which is already producing 50,000 tonnes of kraft lignin annually, making it the largest facility of its kind globally.

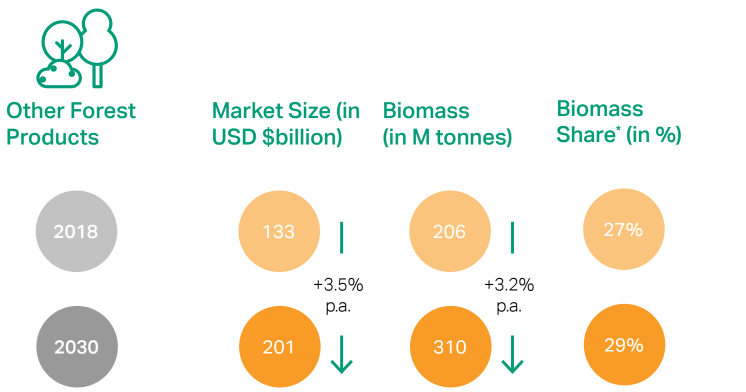
Lignin-based graphite replacements not only gain a sustainability advantage, but they also help in improving battery performance to enable more effective solutions for batteries. This supports the penetration of sustainable energy storage solutions, a key in using renewable energy in mobility and other markets. The global battery market is projected to increase tenfold in the next five years.[39] Using a renewable raw material that is abundantly available—wood—is crucial to finding more sustainable and affordable alternatives to fossil-based, scarce, and expensive materials.

Figure 22: Main biomass sources and value chain stages in focus



4.6 THE BIOECONOMY IN OTHER FOREST PRODUCTS[40]

Figure 23: Growth opportunity in other forest products industry



*On overall material use in industry
Source: European Commission; Oxford Economics; WBCSD; BCG analysis, Member companies

- Total market size is estimated at USD $133 billion
- 27% of material used in the industry is estimated to be biomass, equaling 206 million tonnes of biomass
- Market value is estimated to grow by 3.5% per annum and the biomass volume by 3.2% per annum until 2030, showing that the relative value is almost the same

SPECIFIC INDUSTRY CONDITIONS AND ENABLERS

Forests have multiple benefits for the environment and society besides providing wood as raw material: they can prevent land erosion, provide drinking water and oxygen, and are home to over 80% of terrestrial biodiversity.[41] In addition, they play an important role in climate change mitigation as forests and forest products store carbon for the duration of their lifetime and substitute non-renewable, fossil-based materials.[42]

There are about 4 billion hectares of forest worldwide, with about 30% being used primarily to produce wood and non-wood products.[43] As of today, around 10.7% of the total forest areas are either Forest Stewardship Council (FSC) or Programme for the Endorsement of Forest Certification (PEFC) certified, resulting in only 30% of the total industrial roundwood production in the world being certified.[44] As the demand for wood is expected to triple by 2050,[45] more of the world's productive forest needs to be brought under sustainable management to meet this growing demand sustainably and counter the forces that drive deforestation.

BIOECONOMY INDUSTRY TRENDS

A variety of wood uses
Apart from wood use for construction, packaging, or bioenergy outlined in previous chapters, material use of wood includes traditional products such as paper, furniture, or care products, as well as more innovative biomaterials such as microfibrillated cellulose to be used in specialty papers and the use of wood fibers in composite materials. (See Chapter 4.4.1.)

End-of-life of forest products
Wood fiber is a renewable and biodegradable material; with a global recycling rate of approximately 60%,[46] paper is one of the most recycled materials globally. For fiber to reach its full recycling capacity (around seven times), the input of virgin fiber is necessary at each cycle. Forest products should be first used and reused as materials before being recycled or burnt for energy.

Bio-based chemicals
Through the processing of lignin and cellulose from wood, bio-based chemicals represent a promising new market for forest products with multiple applications such as bio-based aromas for fragrances and flavors, lubricants, natural fertilizers, or cleaners and solvents.

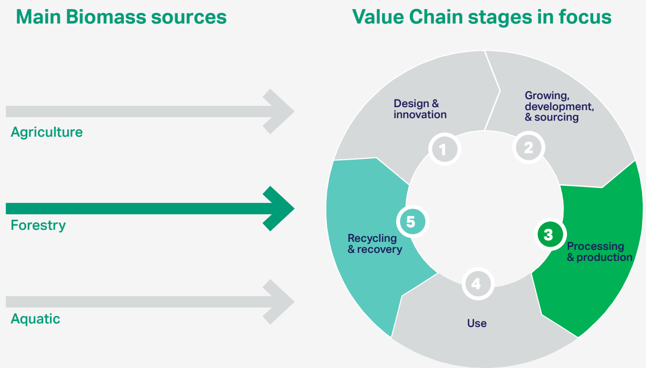
THE NAVIGATOR COMPANY: VALORIZATION OF CARBONATE SLUDGES

The Navigator Company recycles carbonate sludges, a waste product of their pulp processing and production stage. The sludges are partially fed into the lime kiln, to produce white liquor, which, in turn, is used in the production of pulp.

The surplus of carbonate sludges is used as a raw material to be incorporated in the production of Precipitated Calcium Carbonate (PCC), one of the main components of Navigator's wood-free paper, reducing the overall consumption of fresh raw materials.

The PCC production takes place onsite through a cooperation partner. The partnership and colocalization result in several win-win benefits: minimized sludge deposition in industrial landfills and reduced associated cost for Navigator; reduced mining of limestone (the fossil raw material equivalent) and the associated need for supplier management for the partner; and avoidance of transport cost and emissions associated with a traditional sludge disposal and PCC production chain for both sides of the partnership.

Figure 24: Main biomass sources and value chain stages in focus



4.7 THE BIOECONOMY IN ELECTRONICS AND ELECTRICAL PRODUCTS[47]

Figure 25: Growth opportunity in the electronics and electrical products industry

Electronics & Electrical Products	Market Size (in USD $billion)	Biomass (in M tonnes)	Biomass Share* (in %)
2018	117	37	5.3%
	+5.1% p.a.	+5.0% p.a.	
2030	217	67	7.2%

*On overall material use in industry
Source: European Commission; Oxford Economics; WBCSD; BCG analysis, Member companies

- Total market size is estimated at USD $117 billion
- Only 5.3% of material used in the industry is estimated to be biomass, equaling 37 million tonnes of biomass
- Market value is estimated to grow by 5.1% per annum and the biomass volume by 5.0% per annum until 2030, showing that the relative value is similar

SPECIFIC INDUSTRY CONDITIONS AND ENABLERS

There is an increasing demand for consumer products such as electronics and electrical appliances due to a growing world population that will reach nearly 10 billion people in 2050. A shift from the current, largely inorganic electronics industry (predominantly metal and silicon based) to organic electronics offers a sustainable option in regard to future resource management. Organic electronics use carbon-based materials to transmit electricity, such as polymers. Organic electronics use less or no toxic materials and often less energy. At the end of their life span, these can be recycled and/or biodegraded. They also provide a range of other benefits, including flexibility, printability, and potentially more access to affordable electronics, not least in the medical sphere. According to a study conducted by Lancaster University, unobtrusive biosensors for medical health applications (robotics and wearables), smart fabrics, smart packaging, toys, and radio-frequency identification tags used in building key cards are most promising for future research within organic electronics.[48]

Conventional plastics is currently used to satisfy the request for new technologies and appliances. Bioplastics create a huge opportunity for the sector to move away from fossil fuels and respond to public pressure. Design improvements and innovations regarding heat resistance, fire behavior, and longevity can further enable bio-based materials to gain market share in this industry. In addition, price reductions can make bio-materials, such as PLA, more competitive compared to conventional alternatives.

BIOECONOMY INDUSTRY TRENDS

Bio-based electronics and electrics
Producers of electronic and electrical products increasingly make use of bio-based materials, mainly biopolymers such as PLA and PBS. While PLA is expensive, it has been designed to provide superior properties such as combined shape memory and recyclability, a combination that currently available petroleum-based plastics cannot offer.

Bio-casings, enclosures, and others
Applications of biomass-based materials in electronic and electrical products include casings, enclosures, sensors, actuators, optics, shielding, photovoltaics, and displays; one major advantage of the use of biopolymers is their lower production temperature as compared to conventional ones.

Bio-household appliances
Household appliances such as toasters, coffee machines, electric kettles, and vacuum cleaners based on biopolymers are currently being developed for commercial use.

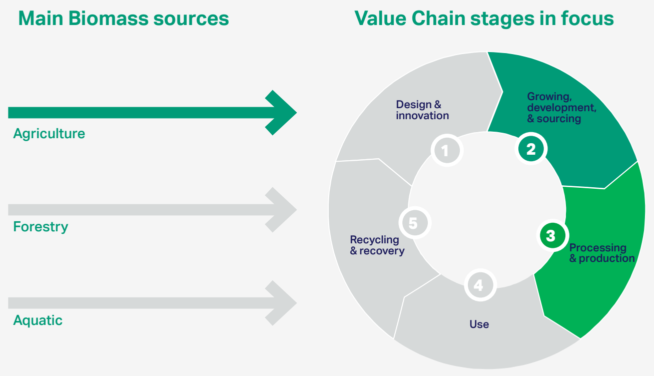
CLARIANT: INNOVATIVE PLASTIC ADDITIVES FROM RENEWABLE FEEDSTOCK ENABLE RECYCLING

Clariant and Neste teamed up to offer a wide range of additives based on Mass Balance-certified ethylene and propylene from renewable feedstock, including waste and residue oils. The derived products from the Terra line, such as Exolit OP Terra or Licocene Terra, feature at least 50% renewable carbon. Exolit OP Terra is used as a flame retardant to engineer plastics for electronic and electrical equipment and automotive components. The flame retardant has the added benefit of not interfering with the plastic recycling process, overcoming an issue common with traditional flame retardant additives, and enabling enhanced recycling rates.

The Licocene Terra range includes waxes for plastic processing and Performance Polymers (LPP) as hot melt adhesives for bonding and debonding, allowing for the cradle-to-cradle recycling of postindustrial and postconsumer waste, such as carpets.

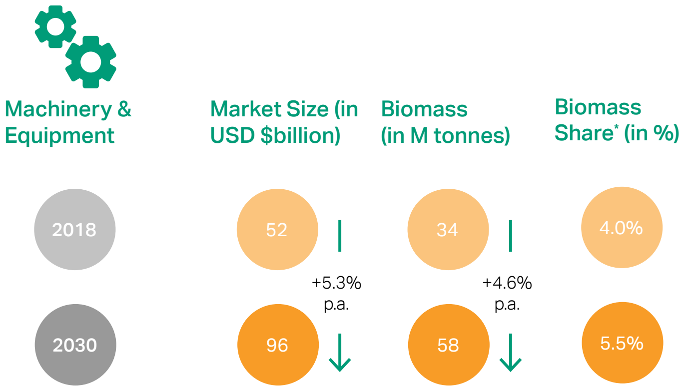
The drop-in replacement products for traditional additives reduce the use of crude oil and hence the associated CO2 emissions, posing as an attractive option for customers to reduce the environmental impact of their plastic product.

Figure 26: Main biomass sources and value chain stages in focus



4.8 THE BIOECONOMY IN MACHINERY AND EQUIPMENT[49]

Figure 27: Growth opportunity in machinery & equipment industry



* On overall material use in industry
Source: European Commission; Oxford Economics; WBCSD; BCG analysis, Member companies

- Total market size is estimated at USD $52 billion
- Only 4.0% of material used in the industry is estimated to be biomass, equaling 34 million tonnes of biomass
- Market value is estimated to grow by 5.3% per annum and the biomass volume by 4.6% per annum until 2030, showing that the relative value is slightly superior

SPECIFIC INDUSTRY CONDITIONS AND ENABLERS

The machinery and equipment industry, including large facilities such as biorefineries and biochemical facilities, play a vital role in the circular bioeconomy. The increasing use of bio-based materials impacts the requirements for machines, plants, and processes as they have to be specifically developed to handle biological materials where the latter are not drop-in replacements.

Resource efficiency, energy requirements, and sustainability are major topics within the industry, which, in turn, enable bio-based solutions to have a competitive advantage. This applies to the machines and facilities themselves, as well as supporting materials such as lubricants and other materials applied. For example, bio-based lubricants are available and drop-in replacements for fossil-based lubricants are being developed. With the global lubricants market sized around USD $165 billion in 2019 and projected to grow to USD $183 billion in 2025,[50] this is a major business opportunity in the face of growing consumer awareness and bears the advantage of disconnecting from fluctuating oil prices.

To enable increasing use of bio-based materials, biorefineries and biochemical facilities play a vital role. (See case study in Chapter 4.9 for further details.) 2015 forecasts predicted that in the US and Europe, 300 to 400 biorefineries are required to enable an industrial bioeconomy[51]—almost double the number of facilities identified in the same year. It is estimated that globally the same doubling in facilities is to be expected, valued at USD $170 billion.[52]

BIOECONOMY INDUSTRY TRENDS

Novel engineering in biorefineries and biochemical facilities
Industrial biotechnology produces a wide variety of products in biorefineries and biochemical facilities, ranging from bio-based chemicals and pharmaceuticals to food additives and cosmetic ingredients. Additionally, with the aid of new production cultures such as microorganisms and algae, bioreactors produce new types of biomaterials.

Biopolymers in engineering
About 20% of all biopolymers are used in industrial engineering, with the application comprising water pipes, cable jacketing, coating cables, and injection molding. The global biopolymer market for industrial use is expected to increase by 5% per year and is anticipated to reach 445,000 tonnes in 2025.

Production of innovative bio-based materials
New developments in injection molding and related processes have paved the way to produce hybrid bio-based materials, such as wood-plastic composites. Additionally, the production of biolubricants, currently only 3% of the overall lubricants market, is increasingly growing.

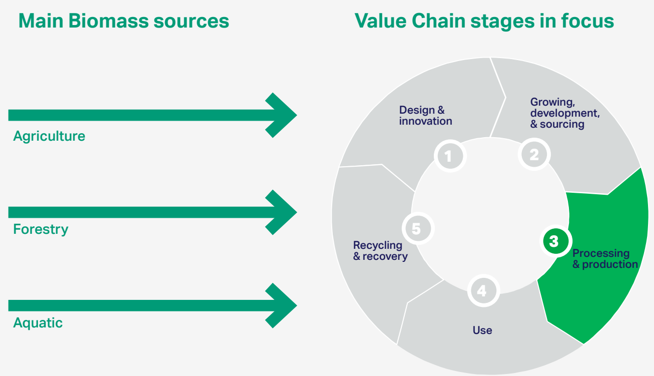
SARTORUIS: MONITORING OF PROCESS STATE AND KEY PARAMETERS IN BIOLOGICAL PRODUCTION

Sartorius has developed a range of solutions in their BioPAT, Biological Process Analytical Technology lineup. The sensor, controller and software lineup allows the continuous monitoring of process state and key parameters in biological production.
Tight, real-time process control helps to overcome raw material variability and the variability of biological processes themselves.

This in turn is a key enabler to develop and scale production of bio-based products such as biopharmaceuticals. Increased transparency and control translates to higher yields, shorter development times and cost savings, lowering some of the key hurdles to overcome when establishing new, bio-based products.

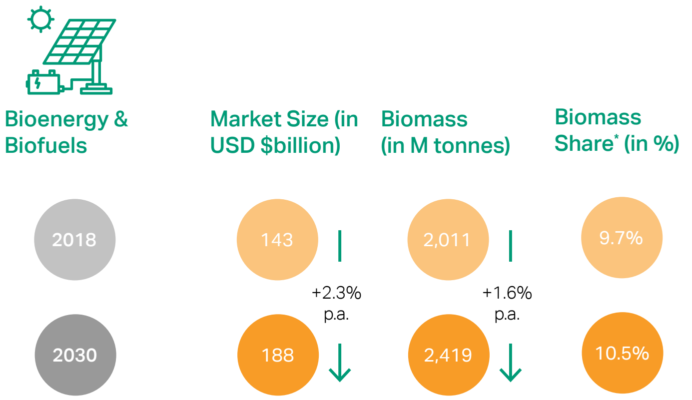
Traditional processes have often grown over time and are based on a rich experience base. New, innovative processes in the circular bioeconomy require re-thinking past approached. Solutions to maximize the efficiency of new processes are of central importance to enabling access to the new markets created in the circular bioeconomy.

Figure 28: Main biomass sources and value chain stages in focus



4.9 THE BIOECONOMY IN BIOMASS ENERGY AND BIOFUELS[53]

Figure 29: Growth opportunity in the biomass energy and biofuels industry



* On overall material use in industry
Source: European Commission; Oxford Economics; WBCSD; BCG analysis, Member companies

- Total market size is estimated at USD $143 billion
- 9.7% of material used in the industry is estimated to be biomass, equaling 2,011 million tonnes of biomass
- Market value is estimated to grow by 2.3% per annum and the biomass volume by 1.6% per annum until 2030, showing that the relative value is slightly superior

Renewable and bio-based energy

Bioenergy—that is, power, heat, or motive power—can be effectively produced from either biomass or biofuels. The main types of biofuels include biodiesel, bioethanol, bioethers, and biogas. They can be based on a variety of crops, plants, and waste. Biomass for direct energy production is, for example, wood residues such as sawdust. For a complete overview, please see the flow chart in Chapter 2.

Despite being based on renewable sources, these types of energy generation technologies using biomass or biofuels receive public scrutiny as they are not always seen as a sustainable alternative to conventional sources due to their potentially high requirement for land, water, and primary energy needs for the production itself. Moreover, potential negative impacts on biodiversity and food production play a role depending on the type of input material used.

SPECIFIC INDUSTRY CONDITIONS AND ENABLERS

Around 80% of all energy supply is based on fossil fuels that significantly contribute to global warming.[54] The science is clear on the need for ambitious climate action to keep temperature increase at a maximum of 1.5°C above pre-industrial levels to avoid devastating impacts on people and nature. Scaling up the use of low-carbon, renewable sources of energy is a key part of the solution. In addition to the needed contribution to limiting climate change, biofuels can trigger technological innovation and benefit local communities.
In Yunnan, Guizhou, China, with the support of CNTC[55] and the local government, PMI[56] is leading an initiative through its suppliers to help local farmers to switch to wood pellets as a primary energy source in curing barns. The newly required pellet production facilities benefit local communities through additional employment and reduced dependency on coal. The program has to date converted more than 70,000 curing barns with a significant reduction on GHG emission from 2.86 kg to 1.86 kg per kilogram cured tobacco by end of 2020.

One enabler for bioenergy to gain more importance in the global energy mix is the shift toward second- and third-generation biofuels that rely on food waste and residues. These input materials decrease the requirement for land use and utilize the cascading principle explained in Chapter 1. In addition, biomass coming from certified sustainably managed forests or agriculture can guarantee that there is no negative impact on biodiversity or nature.

Transport, together with power, is one of the sectors with the highest global biomass demand at 31% each, followed by industry with 21%, and buildings with 20%.

BIOECONOMY INDUSTRY TRENDS

Wood as heating material

Over 50% of all renewable energy is from biomass, out of which the majority originates from wood that can be used as heating material in the form of wood pellets, chips, and shavings.[57] When discussing wood as an energy source, traditional wood burning in stoves and fires is considered less or not at all sustainable in comparison with modern use, for example in modern heating systems or industrial applications. Wood as bioenergy, as well as other types of bioenergy, offer the advantage of generating energy when required; as mentioned in the previous paragraph, a focus on cascading use of wood is key to ensuring the sustainability of this biomass source for energy generation.

Biogas from fermentation

Biogas plants transform energy crops such as maize, animal manure, and other residuals into methane, often referred to as biogas. Organic material waste from this fermentation process can be used as field fertilizers.

Alternative technologies include the gasification of solid biomass, whereby the biomass is gasified in a high-temperature reaction into a mix of gasses that can be used in gas engines or for follow-on processes.

Biofuels for transportation

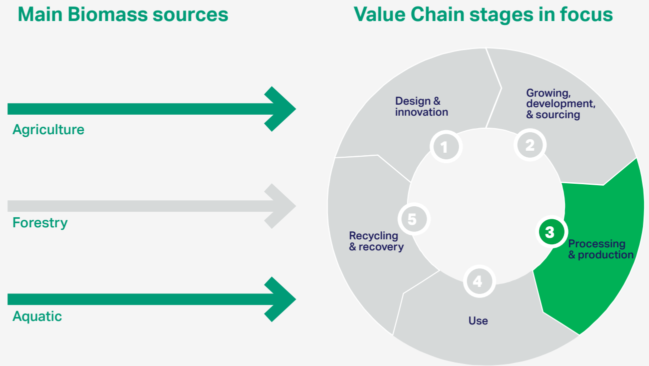
Biofuels obtained from crops (first generation), residues/agriculture waste (second generation), and algae (third generation) are used in automobiles, ships, and aircrafts. Biodiesel is currently the most widely used biofuel type; bioethanol and biomethane are other relevant biofuel types.

ENI: A FLEXIBLE BIOREFINERY

Eni continues to give new life to its existing plant with the second conversion of a traditional refinery into a biorefinery in Gela (Sicily). Launched in August 2019, the plant has a processing capacity of up to 750,000 tonnes a year and will be able to treat increasing quantities of second and third generation inputs, such as used vegetable oil, animal fat, algae, and byproducts to produce high-quality biofuels.

A pretreatment unit supplies the biorefinery with the raw materials, enabling it to treat advanced and unconventional loads up to 100% of processing capacity. This allows to flexibly change inputs as availability fluctuates and is an integral part of Eni's feedstock diversification strategy. The effect is twofold: increased returns through lower raw material cost, and reduced competition over specific materials reducing the likelihood of trade-off effects.

Figure 30: Main biomass sources and value chain stages in focus



4.10 THE BIOECONOMY IN FOOD AND FEED LOSSES AND WASTE FOR COMPOSTING PURPOSES[58]

Figure 31: Growth opportunity in the biomass energy and biofuels industry

* On overall material use in industry
Source: European Commission; Oxford Economics; WBCSD; BCG analysis, Member companies

- Total market size is estimated at USD $2,300 billion
- 98% of material used in the industry is estimated to be biomass, equaling 5,700 million tonnes of biomass
- Both market value and biomass volume is estimated to grow by 1% per annum until 2030, showing that the relative value is the same

Food loss / waste: Food loss refers to any refers to any product that is discarded before it gets to the end consumer due to unintended results in the agricultural or distribution process. "Food waste" refers to the products that are thrown away at the end of the value chain, either at the retailer or final consumer. Both classifications can be applied to feed accordingly. Throughout this report we refer to food and/or feed loss and waste.

According to the UN's Food and Agriculture Organization and the World Resource Institute, food loss and waste accounts for 8% of global greenhouse gas emissions. Around 870 million people around the world are undernourished. Circular bioeconomy practices can thereby support the solution of an environmental and social problem, especially if the saved food can be routed to areas of undernourishment.[59]

There are three main enablers to address this issue:

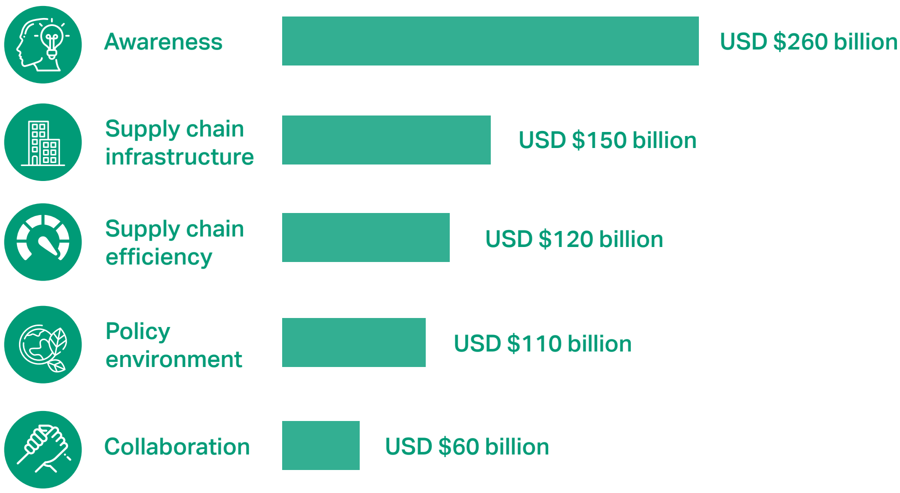
1. Reduce the amount of existing food and feed loss and waste
2. Use existing losses and waste as input materials for products and energy generation
3. Compost existing food and feed loss and waste to enrich the soil without any negative environmental impacts

1) BCG has identified five key levers to reduce the amount of food loss and waste and save up to USD $700 billion. These levers are awareness of the problem across the supply chain, improved supply chain infrastructure, increased supply chain efficiency, collaboration among players across the value chain, and a favorable policy environment (see Figure 32).

2) As mentioned in previous industry chapters, companies start using food and feed losses and waste as new input materials for their products, thus upcycling the waste. Different technologies allow the conversion of food and feed losses and waste into ethanol, biodiesel, and biogas. The economic opportunity for upcycling and energy are both already included in the respective industry analysis, and detailed information on trends and examples can be found there.

3) The third option for food and feed losses and waste is composting. To avoid any negative externalities, effective composting management plays a key role in controlling potential impacts on air and water quality.

Figure 32: Key levers for food loss & waste reduction



BIOECONOMY INDUSTRY TRENDS

Composting to feed the soil

The transformation of biological waste into fertilizer through composting is a mature technology that is performed for centuries. Microbes break down the organic matter into carbon dioxide, water, and heat. Once decomposed, the fertilizer can be used to improve the physical conditions of the soil. This is not only limited to food and feed waste and loss but can also extend to agricultural waste and other compostable waste, for example suitable paper, cardboard, or cellulose fabrics.

Development of new collection methods and services

Separation of food and feed waste at the source is critical to ensure a clean feedstock for composting and allow the final product to meet quality standards and be suitable for sale or use. Countries and municipals are setting up new, distinct collection methods to separate food and feed waste from the general household waste. In addition, companies offer composting services to restaurants, cities, or individuals.

Innovation to improve composting strategies

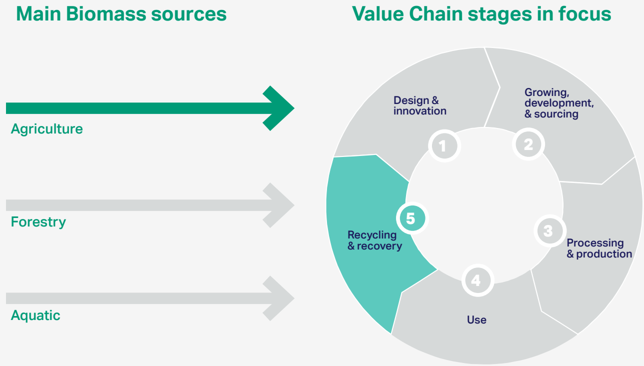
Companies also innovate in the field of organic or inorganic additives, microbiological variations, and the mitigation of gaseous emissions to improve food waste composting. These innovations can decrease the composting time and increase compost quality.

IFF: FINDING A BETTER USE FOR CITRUS PEEL WASTE

IFF has partnered with a Dutch startup, PeelPioneers, to utilize fresh orange peels that would otherwise be discarded from supermarkets, juice bars, and other quick-service restaurants in the Netherlands. While orange peels cannot be composted as easily as other fruits and vegetables and are not easily incinerated due to their high water content, they are naturally rich in highly prized essential oils. Thanks to PeelPioneers' agreement with one of the largest commercial waste management companies in the Netherlands, discarded fresh peels are delivered to the PeelPioneers factory within 72 hours of juicing, where they are washed and treated to obtain a high-quality, oil-in-water emulsion via cold extraction. IFF uses the essential oil to create signature taste designs, including natural orange flavorings and extracts.

Utilizing circular design principles in this way is saving resources and creating a unique marketing advantage for IFF's Re-Imagine Citrus Upcycled Orange product line.

Figure 33: Main biomass sources and value chain stages in focus



5 Current obstacles and suggested solutions

5 Current obstacles and suggested solutions

Despite the vast business benefits and opportunities that a circular bioeconomy offers, it has not yet developed its full potential or reached the scale needed for meaningful impact.

Specific barriers impair developing or scaling up bioeconomy solutions, such as potential costs, technological issues, awaiting policy support, and ambiguous public perception. Ways to overcome these barriers are outlined in Chapter 5.1.

In addition, certain sustainability and economic trade-offs need to be considered to ensure the economic feasibility and superior sustainability performance of circular bio-based solutions compared to conventional alternatives. In Chapter 4, selected trade-offs were called out on an industry basis. Chapter 5 provides a general overview of the sustainability and economic principles to consider for a circular bioeconomy and discusses the topic of trade-offs with a wider view. The high-level checklist provided at the end of this chapter is aimed at supporting companies answering the most essential questions concerning these principles.

5.1 POTENTIAL BARRIERS TO SCALING CIRCULAR BIOECONOMY AND SUGGESTED SOLUTIONS

To evaluate potential barriers to scaling a circular bioeconomy, we have conducted interviews with businesses active in this market and prioritized the experienced barriers based on the perceived company importance. Four barriers were ranked highest:

1. **Financial Flows.** The initial investments needed for a transformation can be considered too high
2. **Technology.** The implementation of technology or availability of viable technology may not be sufficient
3. **Policy and Regulation.** Required public support and regulation may not yet fully be in place and subject to policy adaptions
4. **Mindset and Values.** Public opinion on bio-based material is often still ambiguous and customers are rarely willing to pay a price premium

In the following paragraphs, we present recommendations to support companies in overcoming these four key barriers.

1.
Financial Flows - Weigh long-term savings and risk reduction against potentially high initial costs. To understand the total cost impact of circular bio-based solutions, companies need to assess both the expected additional or initial costs as well as cost-saving opportunities. Additional costs may occur, for example, from investments into new assets to process biomass or from higher costs for feedstock for the production of bio-based intermediates suitable for further processing. However, in the long-term, cost savings may make the initial investment profitable. For example, the company can incur lower costs for input materials due to waste recycling, or the cost for sewage treatment can be reduced based on bacterial treatment of wastewater. Additionally, a stable material input reduces the risks and associated costs related to abrupt raw material scarcities and gaps that might occur in the fossil-based supply chain.

2.
Technology - Focus on technological solutions as the center of the transformation. Incorporating new technological developments as part of the corporate bioeconomy vision and strategy supports companies in tackling potential hurdles from the beginning. This way, technological solutions are at the center of the transformation and seen as a prerequisite the whole company is working on. Moreover, they open opportunities for new business

models and additional revenue streams based on service models or product innovations. A hot spot for such innovation is the technology and infrastructure needed at the end-of-life of circular bioproducts to support a bioeconomy—for example, turning waste back into a resource is a challenge poorly addressed in the current economic system.

3.
Policy and Regulation - Leverage and advocate for required public support and regulation. Companies can benefit from governmental subsidies or other forms of support, such as taxation, that stimulate the utilization of bio-based materials and the reduction of the carbon footprint. This support can help companies overcoming existing barriers, such as initial investments or additional costs. The following deep dive gives an overview of existing and upcoming policies. Additionally, companies can actively collaborate with regulators and NGOs to showcase the positive impacts of circular bio-based products and further stimulate required policy changes. Once decided, policies play a vital role in protecting the investments made in bio-based solutions, and legislation is required to ensure that bio-based solutions are subject to the same and not increased scrutiny over their conventional alternatives.

4.
Mindset and Values - Educate consumers about higher quality and sustainability. The public opinion on bio-based material is often still ambiguous and customers are rarely willing to pay a price premium. Companies can increase the perceived value-add of their products through educating consumers about higher quality and energy efficiency, or longer life span of bio-based products compared to fossil fuel alternatives. The checklist in Chapter 5.3 provides a starting point for companies to evaluate and communicate the superior sustainability performance of circular bio-based products.

In general, to enable a successful transformation toward a circular bioeconomy, collaborations across sectors need to be established and strengthened to benefit from existing expertise and know-how and ultimately accelerate the transition to a circular bioeconomy.

5.1.1 DEEP DIVE: BIOECONOMY POLICY LANDSCAPE

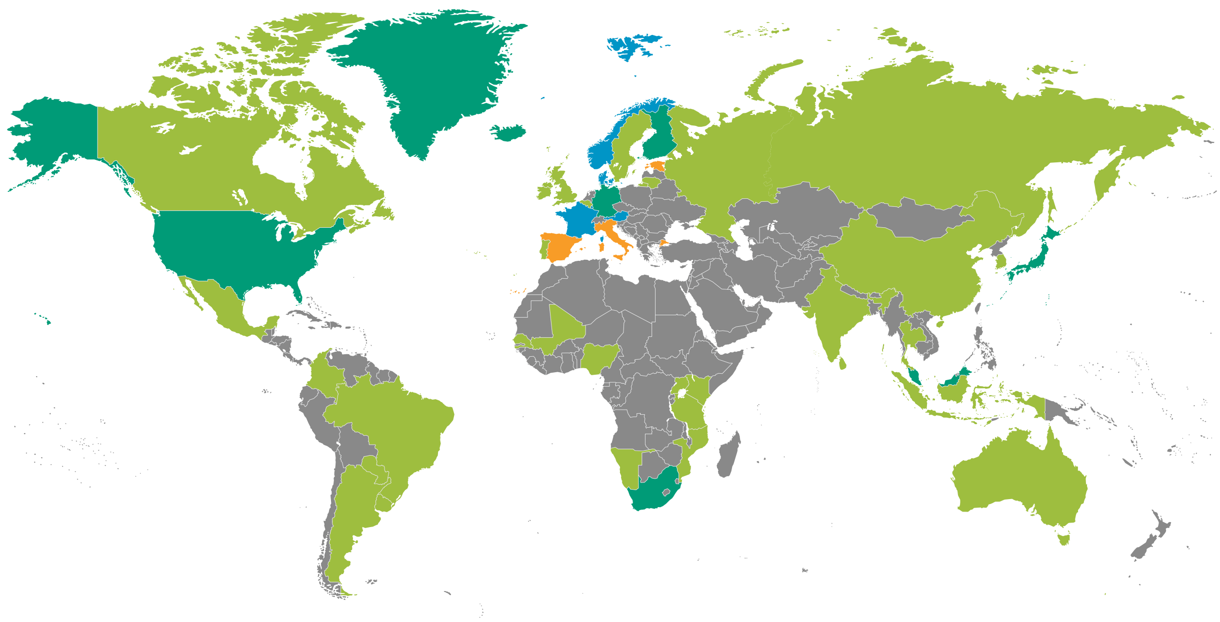
Policy adaptions can significantly support companies in the transition toward a circular bioeconomy, as stated above. The definition, level of detail, importance, and goal of the strategies vary across the countries.

> In 2018, there were around 50 countries with a bioeconomy-related or dedicated strategy. (See Figure 34.)

Definition. Some countries explicitly include circularity in their definition for a bioeconomy, such as the EU Bioeconomy Strategy[60] and the EU Circular Economy Action Plan.[61] Others include bioeconomy aspects in their broader strategy for sustainable development but do not have a dedicated bioeconomy strategy.

Level of Detail. The implementation details of the bioeconomy (-related) strategy differ per country, from high-level goals and aspirations to concrete action plans. A range of countries, such as the UK, Australia, and China, have set quantitative targets to operationalize high-level ambitions. However, only a few countries, such as Thailand, France, and Spain, have an action plan in place detailing how to implement the defined strategies. And even fewer countries, such as Thailand and Spain, have set specific budget plans.[62]

Figure 34: About 50 countries around the world already have a (dedicated) bioeconomy strategy or are currently developing one



Goal. Countries foster the transition toward a circular bioeconomy through different types of support and goals. We identified five focus areas for support, with an overview of the strategies per country in Figure 34:

1. Promoting innovation. Public approaches fostering innovation vary, from more traditional approaches concerning low-tech innovation or open innovation platforms to more advanced technology-driven approaches such as targeting bionics, AI, and carbon capture.

2. Supporting infrastructure. Infrastructure support can start with educational approaches, for example, by showcasing a biorefinery pilot plan as done in Thailand. And they can go further by fostering collaboration and knowledge exchange through establishing bioeconomy hubs or networks. Fostering such cross-industry symbiosis is especially important for circular approaches, where waste from one industry can serve as raw material for another.

3. Supporting capacity formation. For capacity building, countries mainly offer educational programs on various levels, such as schools, universities, and postgraduate programs.

4. Supporting commercialization. Commercialization is mainly supported through early financial support—such as angel or venture capital funding—or facilitation of required marketing, scale-up, or export. Only a few countries enable subsides for goods based on renewable resources. An additional driver for commercialization is prizing in externalities such as GHG emissions.

5. Supporting the demand side. The demand side of bio-based products is fostered by public procurement policies, supported certifications, and standardized labels in many countries. Only a few countries offer tax reductions on a customer-level, quota for biobased products like biofuels, or ban fossil-based products. Interviews and secondary research analysis allowed the identification of significant gaps in the existing policy landscape. The German bioeconomy council, for example, emphasizes the need for more concrete actions on the consumer-end regarding detailed information on bio-based products and related consumer benefits. Additional gaps include the lack of bioeconomy-friendly framework conditions, for example, the difficulty to remove fossil fuel subsides,[63] and insufficient international collaboration and knowledge sharing to set up a favorable policy environment.

Figure 35: National policy measures for promoting bioeconomy particularly strong in capacity building, stimulating R&D, and infrastructure...

% of countries	Key Points	Practical and proposed policy measures	Americas				Asia/Pacific				Europe					
			Argentina	Brazil	Canada	USA	Australia	China	New Zealand	Thailand	France	Italy	Latvia	Norway	Spain	UK
64%	Promoting innovation	Public R&D	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		Traditional knowledge and low-tech innovations			●			●	●							
		Stimulating private actor R&D(e.g., through public–private partnerships)	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		Social innovation (e.g., open science, citizen science)				●			●		●				●	
		Research networks, consortia, CoE, etc.	●	●	●	●		●		●	●			●	●	●
61%	Supporting Infrastructure	Bioeconomy hubs, networks, cluster			●	●		●		●	●	●		●	●	
		Investment for R&D facilities and equipment	●	●	●	●		●	●	●	●	●	●	●	●	
		Investment in the digital infrastructure				●			●							●
		Urban greening projects			●			●				●				
		Pilot and demonstration facilities	●	●		●	●	●			●	●	●	●	●	●
		Biorefinery demo plants	●	●	●	●	●	●	●	●	●	●	●	●	●	●
82%	Supporting capacity building and education	Capacity building(e.g., trainings for professionals)	●	●	●	●		●	●	●	●	●	●		●	●
		Bioeconomy education programs(including masters and doctoral programs)	●	●	●	●		●		●	●	●	●		●	●
45%	Supporting commercia-lization	Access to capital for bio-based companies	●	●	●	●	●	●		●	●		●	●		●
		Tax incentives for bio-based companies	●		●	●	●	●	●	●	●	●	●	●	●	●
		Knowledge and technology transfer	●	●		●	●	●	●	●	●	●	●	●	●	●
		Access to scale-up facilities		●		●		●				●				●
		Export promotion policy						●					●		●	
		Development and marketing efforts(e.g., feasibility studies)			●	●	●	●	●		●		●		●	●
		Subsidies for (increased production and use of renewable resources)						●						●		

Note: Proportion of boxes indicative for global biomass shares (2018); smaller shares (<5%) enlarged for visual demonstration
Source: Eurostat; Freedonia; OECD; WU Vienna; BCG Analysis

Figure 36: ...But with gaps in framework conditions as well as International collaboration and knowledge sharing

			Americas				Asia/Pacific				Europe					
% of countries	Key Points	Practical and proposed policy measures	Argentina	Brazil	Canada	USA	Australia	China	New Zealand	Thailand	France	Italy	Latvia	Norway	Spain	UK
40%	Supporting the demand-side	Bio-based public procurement policy	●		●	●	●	●		●	●	●	●	●	●	
		Certification and labels on a product's life cycle impact (e.g., footprint)	●	●	●	●		●	●		●	●	●	●	●	
		Consumer information and communication campaigns	●		●	●	●		●		●	●	●	●	●	●
		Price-setting				●			●	●	●	●				
		Tax incentives									●					
		Fuel quality standards		●			●									
		Ban of fossil-based products (e.g., plastic bags)														
19%	Ensuring bioeconomy-friendly framework conditions	Removal of fossil fuel subsidies												●		
		Policies for sustainable development	●													
		Review of IP regulations		●				●	●	●						●
		Bioprospecting regulations												●		
		Global data policies (e.g., open data commons policies)							●							
		Review and harmonization of biotechnology policies	●		●	●		●	●							●
		Regulations for sustainable biomass production and utilization			●							●	●	●		
		Regulatory framework for bioenergy	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		Carbon tax			●											
		Circular economy regulations (recycling quotes, use of byproducts, ecodesign, life cycle assessment of patents			●							●			●	
		Regulations for the uses of bio-based materials in construction			●						●		●	●		
		Development of regional bioeconomy policy strategies	●												●	

Note: Proportion of boxes indicative for global biomass shares (2018); smaller shares (<5%) enlarged for visual demonstration
Source: Eurostat; Freedonia; OECD; WU Vienna; BCG Analysis

% of countries	Key Points	Practical and proposed policy measures	Americas				Asia/Pacific				Europe					
			Argentina	Brazil	Canada	USA	Australia	China	New Zealand	Thailand	France	Italy	Latvia	Norway	Spain	UK
30%	Promoting good governance	Interministerial and interregional cooperation	●			●	●			●		●			●	
		Monitoring and measuring activities	●	●	●	●	●	●	●		●	●	●			●
		Evaluation of policy programs	●			●			●							
		Public reporting and multi-stakeholder dialogue	●			●					●	●			●	
		Learning and adaptive policy														
		Level playing field for bio-based businesses											●	●		
		Bioeconomy advisory council	●								●					
16%	Enhancing international collaboration in the bioeconomy	Harmonization in international trade and policy frameworks	●													
		Knowledge sharing between industrialized and developing countries														
		Private investment in developing countries														
		International monitoring (e.g., satellite tracking)													●	
		Interregional policy dialogue	●									●				
		Bi-and multinational cooperation	●			●		●			●		●	●	●	
		International R&D cooperation		●				●					●	●		●
Country overall measure coverage			55%	41%	48%	56%	27%	53%	35%	36%	54%	44%	47%	34%	51%	48%

Source: Canada's Bioeconomy Strategy (2019); German Bioeconomy Council (2018); Presidency of council of Ministers, Italy (2020); BCG analysis

5.2 COMMON SUSTAINABILITY TRADE-OFFS IN A CIRCULAR BIOECONOMY

The implementation of circular bio-based business models can lead to sustainability trade-offs. A holistic evaluation is required to assess if the overall sustainability of a new bio-based product is better than a conventional alternative, although the sustainability of individual steps in the value chain or individual categories may be worse for the bio-based product. In many cases, such an evaluation should also include a local aspect to better understand if a certain trade-off is acceptable or not. For example, if the trade-off of a material use is the increased water consumption, this may be acceptable in an overall positive sustainability scenario in a location where water is ample, while it is an exclusion criterium in an arid region.

One of the best-known examples of a trade-off related to the bioeconomy is the competition for agricultural lands, between the use for food and feed and the use in biofuels or other industrial feedstock, as illustrated by a quote from Bill Gates:

"If you're using first-class land for biofuels, then you're competing with the growing of food. And so you're actually spiking food prices by moving energy production into agriculture", Bill Gates[64]

This quote highlights one of several common perceptions and trade-offs that companies need to consider when ensuring the sustainability performance of bio-based solutions. Others include agriculture-driven deforestation, illegal or unsustainable sources of wood, negative impacts on biodiversity, and the social impacts associated with structural changes in the economy. The checklist presented at the end of this chapter in Figure 38 will help navigate these trade-offs by providing a list of sustainability and economic principles to consider. A sustainability assessment, such as a life cycle assessment, can help gather the required information to address the criteria. Companies should evaluate their circular bioeconomy decisions understanding the full environmental and social consequences across the life cycle.

Not all boxes must be ticked for a product to be a viable alternative to existing solutions. There are some factors that are critical and cannot be neglected (green circles) and other ones that are supporting the superior performance of the product, but do not necessarily all have to be checked (orange circles).

Evaluation should occur over the whole life cycle and possibly value chain and must include sustainability aspects such as material type (bio-based versus fossil-based), overall resource intensity, emissions, durability, reuse options, or human behavior, and also social aspects such as effects on employment, living conditions, and food availability.

5.3 KEY SUSTAINABILITY PRINCIPLES TO START THE CIRCULAR BIOECONOMY JOURNEY

A list of sustainability and economic principles was created to guide companies at the start of their journey in understanding the relevant circular bioeconomy principles and trade-offs. These are built around four key pillars: Circular Bioeconomy, Environmental Value, Societal Value and Corporate & Stakeholder Value. The list of factors to consider is divided into critical factors and supporting factors. These factors are not prescriptive and not all of them need to be fulfilled for a circular bioeconomy product to be considered sustainable. They should form part of a holistic trade-off assessment.

Figure 37: Four key principles to ensure a superior sustainability and economic performance of products from the circular bioeconomy

SUSTAINABILITY PRINCIPLES			ECONOMIC PRINCIPLES
1. CIRCULAR BIOECONOMY	**2. ENVIRONMENTAL VALUE**	**3. SOCIETAL VALUE**	**4. CORPORATE & STAKEHOLDER VALUE**
Biological resources are renewable, regenerated sustainably, reused, and recovered	Environmental services and values are maintained, conserved, and/or enhanced; negative environmental impacts are avoided, reduced, or restored	Societal value is maintained or enhanced for employees, communities, customers, and consumers across the whole supply chain	Long-term economic viability is maintained or enhanced while providing value for corporate and societal stakeholders
Bio-based resources a) Use bio-based raw materials **Circular[a] resources** b) Ensure circularity of product c) Design waste out of the system d) Use resources at highest cascading level possible[b]	**Energy and climate** a) Emit less emissions (GHG emissions, air pollution) compared to alternatives b) Provide opportunities for carbon storage and sequestration **Nature** c) Avoid, reduce, and restore any negative environmental externalities d) Maintain, conserve, and enhance biodiversity **Water** e) Improve water management practices compared to alternatives	**Employees/Communities** a) Respect workers' rights and well-being across the value chain b) Ensure safe employment conditions c) Provide equal and fair payment d) Ensure a diverse and inclusive workforce e) Support (impacted) communities **Consumers** f) Safeguard consumer welfare g) Provide accurate product transparency	**Economic feasibility** a) Assess the technical feasibility b) Ensure a positive business case c) Confirm support by existing and future policies/regulations **Stakeholder value** d) Adhere to existing certifications or go beyond e) Create transparency, traceability, and establish required collaborations

a. Circularity definition: The circular economy is an economic model that is regenerative by design.

The goal is to retain the value of the circulating resources, products, parts and materials by creating a system with innovative business models that allow for renewability, long life, optimal (re)use, refurbishment, remanufacturing, recycling and biodegrading.

By applying these principles, organizations can collaborate to design out waste, increase resource productivity and maintain resource use within planetary boundaries.

b. E.g., no downcycling/energy recovery of resources if not required; non-renewable, virgin material only used if there is no suitable secondary material alternative

1. CIRCULAR BIOECONOMY

CIRCULAR BIOECONOMY BIOLOGICAL RESOURCES ARE RENEWABLE, REGENERATED SUSTAINABLY, REUSED, AND RECOVERED

BIO-BASED RESOURCES

a) Use bio-based raw materials

- The vast majority of raw materials come from sustainably managed, continuously renewable agriculture, forestry, or aquatic sources
- All bio-based resources used are regenerated by natural systems at a rate that is securing a constant, productive, and healthy stock of the raw material/population and in line with the Planetary Boundaries
- Make use of secondary biomass where possible

CIRCULAR RESOURCES

b) Ensure circularity of product

Value chain/cycle

- The product is designed in a way that makes it repairable, usable for long periods of time, reusable, renewable, refurbishable, remanufacturable, and recyclable or compostable at the end of its lifetime
- The product cyclability is not destroyed or diminished at a later point in the value chain/cycle
- During production of the product, closed resource loops for energy, water, and waste are ensured
- The product life cycle is extended by repairing, reusing, upgrading, and reselling
- The raw materials of the product are recovered, recycled, and/or composted at the end of the product's total life

Business model

- Instead of ownership, paid product access is offered, allowing the company to retain the benefits of circular resource productivity or ownership to increase product use
- Product users are connected to one another to encourage shared use, access, or ownership to increase product use

c) Design waste out of the system

- Minimize waste (sourcing, production, use, end-of-life), ideally less waste is produced compared to non-bio-based substitutes (or similar levels)
- Waste to landfill is minimized

d) Use resources at highest cascading level possible

- Resources are used at the highest cascading level possible (e.g., no downcycling/energy recovery of resources if not required; virgin material only used if there is no suitable secondary material alternative)

● Critical factors (as many of these as possible should be fulfilled)

● Supporting factors (some of these should be fulfilled)

2. ENVIRONMENTAL VALUE

ENVIRONMENTAL VALUE ENVIRONMENTAL SERVICES AND VALUES ARE MAINTAINED, CONSERVED, AND/ OR ENHANCED; NEGATIVE ENVIRONMENTAL IMPACTS ARE AVOIDED, REDUCED, AND RESTORED

ENERGY AND CLIMATE

a) Emit less emissions compared to alternatives

Energy & GHG emissions

- Less scope 1 and 2 GHG emissions are released compared to non-bio-based alternatives (or similar levels)[1]
- Less scope 3 GHG emissions are released across the supply chain compared to non-bio-based alternatives (or similar levels)[1]
- Renewable energy sources are used as much as possible for energy consumption
- GHG emissions are recycled or captured

Air

- Less air emissions (non-GHG) and nanoparticles are released compared to non-bio-based alternatives (or similar levels)

b) Provide opportunities for carbon storage and sequestration

- Use of natural climate solutions—i.e., restoration and creation of carbon-storing environments such as forests, mangrove swamps, peat bogs, salt marshes, and seagrass beds—is maximized
- Carbon storage is measured and maximized

NATURE

c) Avoid, reduce, and restore any negative environmental impacts

Land/Forest/Marine environment

- The land use does not compete with food production
- Deforestation in the supply chain is rigorously traced and eliminated
- No natural forest/habitat is converted to other land uses (e.g., plantations/ grazing)
- Soil health and productivity is maintained or enhanced to prevent soil degradation
- Marine environments are protected

Chemicals

- Use of sustainable chemicals as share of overall chemicals use is maximized
- Use of fossil-based chemicals is minimized
- Use of toxic chemical inputs is eliminated

d) Maintain, conserve, and enhance biodiversity

- Rare and threatened species are protected
- High Conservation Value (HCV) areas are protected and/or restored
- No net biodiversity loss is secured on a regional basis
- Biodiversity, including animal and plant species, wildlife habitats, and natural or ecological community types, is restored and improvements are measured and managed

WATER

e) Improve water management practices compared to alternatives

- Less water is consumed compared to non-bio-based substitutes (or similar levels)
- Discharged water is cleaner compared to non-bio-based substitutes (or similar levels) as wastewater treatment is implemented
- The risk of chemical runoffs is minimized
- A context-based water stewardship approach is applied that conserves and protects groundwater and surface-water resources
- The capacity of soils to hold water is measured and improved

● Critical factors (as many of these as possible should be fulfilled)

● Supporting factors (some of these should be fulfilled)

1. Scope 1,2 and 3 GHG emissions to be considered holistically, e.g. significantly lower emissions in scope 1 and 2 may justify slightly higher scope 3 emissions

3. SOCIETAL VALUE

SOCIETAL VALUE IS MAINTAINED OR ENHANCED FOR EMPLOYEES, COMMUNITIES, CUSTOMERS, AND CONSUMERS ACROSS THE WHOLE SUPPLY CHAIN

EMPLOYEES/COMMUNITIES

a) Respect workers' rights and well-being across the value chain

Human & labor rights

- Human, labor, land rights, and fundamental freedoms[1] of those affected by the product are respected, protected, and fulfilled
- No child labor[2], forced labor, or human trafficking is practiced along the product's value cycle
- Access to grievance resolution mechanisms is ensured for individuals affected by the product
- Indigenous peoples' legal and customary rights of ownership, use, and management of land affected by the product are identified and upheld[3]
- Labor associations and collective bargaining are allowed

Well-being

- The social and economic well-being of workers and farmers is maintained or enhanced
- Local skills of people producing the product are developed

b) Ensure safe employment conditions

- Safe and healthy working conditions in line with the ILO conventions are ensured along the product's value cycle

c) Provide equal and fair payment

- Salary across the product's supply chain is above the living wage—adhering to geographical differences
- Fair working hours are respected to produce product
- Equal remuneration is ensured throughout the production process[4]
- For the product, opportunities for economically disadvantaged individuals are created

d) Ensure a diverse and inclusive workforce

- Discrimination on the basis of race, color, sex, religion, political opinion, and national extraction of social origin3 is eliminated

e) Support (impacted) communities

- Adverse impacts on communities (from growing, producing, processing, or sales) are addressed through appropriate remediation processes
- The social and economic well-being of local communities, including farmers, growers, and forest owners, is maintained or enhanced through the product

CONSUMERS

f) Safeguard consumer welfare

- Consumer welfare is safeguarded and considered a top priority when designing, producing, and selling the product

g) Provide accurate product transparency

- Product, processing, and raw material information is comprehensive, accessible, and understandable for consumers

● Critical factors (as many of these as possible should be fulfilled)

● Supporting factors (some of these should be fulfilled)

1. At a minimum those expressed in the International Bill of Human Rights and in the ILO's Declaration on Fundamental Principles and Rights at work
2. In line with ILO C138 Minimum age and ILO C182 - Worst forms of child labor
3. In line with ILO C169 - Indigenous and tribal peoples
4. In line with ILO C100 - Equal remuneration

4. CORPORATE & STAKEHOLDER VALUE

CORPORATE & STAKEHOLDER VALUE LONG-TERM ECONOMIC VIABILITY IS MAINTAINED OR ENHANCED WHILE PROVIDING VALUE FOR CORPORATE AND SOCIETAL STAKEHOLDERS

ECONOMIC FEASIBILITY

a) Assess the technical feasibility

Analysis

- The technical requirements for the production of the product are understood and can be realized sustainably (e.g., energy needs)
- Production can be scaled up to fulfill expected demand (without overexploiting natural resources)

b) Ensure a positive business case

- Market demand exists or is created through the new solution
- A positive business case exists (e.g., based on one of the following points)
- New markets and customer segments are entered
- A competitive advantage can be established, e.g., through attracting and retaining talents and new customers
- Regulatory, societal, and corporate risks (e.g., resource risks, supply chain risks, financial risks) can be mitigated

c) Confirm support by existing and future policies/regulations

Law compliance

- The product complies with all applicable laws, regulations, and nationally-ratified international treaties, conventions, and agreements

Existing support

- The product fulfills current standards (e.g., building material standards, fire standards), enabling potential users to switch
- The product is supported by existing subsidies, tax breaks, etc.

Future support

- The product will fulfill future likely regulations, reducing the user's risk to switch
- Future regulations are likely to be implemented (e.g., alternative to product expected to be banned)

STAKEHOLDER VALUE

d) Adhere to existing third-party certifications or go beyond

- **Social:** Raw material is certified by Fairtrade or a similar certification
- **Agriculture:** Raw material is certified by the rainforest alliance, UTZ, RSPO, as organic or a similar certification
- **Forestry:** Raw material is certified by FSC, PEFC, or a similar certification
- **Aquaculture:** Raw material is certified by ASC, MSC, BAP, or a similar certification
- **Beyond:** New product standards are actively supported and/or shaped

e) Create transparency, traceability, & establish required collaborations

- Traceability/transparency of the product is guaranteed across the whole supply chain
- Stakeholder dialogues concerning the product are organized
- Partnerships established within supply chain
- Partnerships established outside supply chain

● Critical factors (all need to be fulfilled if possible, exceptions have to be part of a trade-off analysis)

● Supporting factors (multiple but not all need to be fulfilled)

5.4 FOUR HIGH-LEVEL ACTION POINTS FOR COMPANIES TO START THEIR CIRCULAR BIOECONOMY JOURNEY

Each company is different and has its unique benefits and challenges—similarly, the circular bioeconomy journey will look different for each one. To support companies in their individual transformation toward a circular bioeconomy, we developed four high-level action points with seven concrete steps, detailed below and illustrated in Figure 38.

1.
Identify entry point:

- **Ensure that the CEO and board are supporting the circular transformation** and, as such, represent ambassadors for the circular bioeconomy.
- **Set clear targets, identify processes and products** within the company which are suited for the circular bioeconomy, and **develop an actionable roadmap**. This should be based on an in-depth understanding of the company's baseline level of circularity. Such a baseline can be achieved by assessing the inflow of resources, slow flow (how long the resources are used or cycled), outflow of resources, and selected qualitative aspects of a company, such as tools and processes or participation in cross-industrial initiatives, for example, the [WBCSD's Circular Transition Indicators (CTI)].[65]

2.
Evaluate sustainability trade-offs:

- **Conduct assessments** of the sustainability performance of circular, bio-based products to understand the underlying trade-offs. To guide companies along the most critical social, environmental, and economic considerations, a checklist across four main principles was developed and can be found in Chapter 5.3. Sustainability analyses, such as a life cycle assessment, can support the checklist completion by providing the data needed to address key questions.

3.
Collaborate:

- **Identify partners** to turn (waste) streams into value streams and collaborate actively with them. One example for this opportunity was shown in the Nutrient Upcycling Alliance created by Veolia and Yara, in which food waste is utilized to produce high-quality fertilizers and soil improvers for regenerative agriculture.
Collaboration is also at the core of international agreements about the shared use of the biological diversity of our planet, such as the Nagoya Protocol.[66]
- **Actively communicate** the bioeconomy achievements **and celebrate success** to motivate employees, attract new customers, strengthen existing relationships, and satisfy investors.

4.
Start small, then scale:

- **Educate and empower employees** across all business units to ensure that values of the circular bioeconomy are lived throughout the organization.
- **Develop new product innovations with clear business cases** that pave the way for disruptive business models. For this, companies need to evaluate the whole value cycle, from design to end-of-life and take-back mechanisms. Such holistic and transformative innovations will help to scale the circular bioeconomy.

Figure 38: Four high level action points

1 Identify entry point

Set clear targets and identify processes and products which are suited for circular bioeconomy

2 Evaluate sustainability trade-offs

Conduct assessments that support the evaluation of sustainability trade-offs (e.g., life cycle assessment)

3 Collaborate

Collaborate and find partners to turn waste streams into value streams. Working with all value chain partners, from sourcing, to product design, to policy makers and consumers

4 Start small, then scale

Start to develop new product innovations with clear business cases that pave the way for disruptive business models and bring your customers to the circular bioeconomy

6 Concluding remarks

6 Concluding remarks

In a circular bioeconomy, (secondary) renewable, biological resources are cycled in closed loops, ensuring a continuous reuse of products and materials, as well as recycling or composting at the end of their life. This alternative economic system provides a sustainable way to shift from fossil-based materials. It should be supported by public policy and implemented by corporates due to both environmental need and economic opportunity.

Economic opportunity. The circular bioeconomy offers a significant business opportunity with an expected market growth of USD $7.7 trillion by 2030. Approximately one-third of this opportunity comes from food and feed waste. The remaining potential lies within product industries—primarily pharmaceuticals, textiles, building materials, and packaging. Companies incorporating circular bio-based solutions can expect increased financial performance, improved risk mitigation, and higher customer as well as employee attraction and retention.

Environmental urgency. The global economy is expected to grow further due to an increasing world population and rising average income. Based on this growth, the amount of resources required per year is expected to double from 2017 to 2050, with 75% of the materials continuing to be fossil-based.[67] This development is risking that we reach our planet's boundaries. Climate change, biodiversity loss, land use change, food loss and waste, as well as resource scarcity are all results of our linear economic systems.

Increasing sustainability and waste awareness, a shift away from conventional plastics, and the drive to decarbonize supply chains all fuel the transition toward a circular bioeconomy. However, barriers remain.

To ensure the superior sustainability performance, trade-offs must be evaluated carefully to change the public perception toward biological solutions. The four principles for a circular bioeconomy provided in this report can support companies in this evaluation as they ensuring that:

1. Biological resources are renewable, regenerated sustainably, reused, and recovered.
2. Environmental services and values are maintained, conserved, and/or enhanced. Negative environmental impacts are avoided, reduced, or restored.
3. Societal value is maintained or enhanced for employees, communities, customers, and consumers across the whole supply chain.
4. Long-term economic viability is maintained or enhanced while providing value for corporate and societal stakeholders.

On a micro-level, companies need to prioritize bio-based, renewable input materials and strive for circularity to capture the benefits of a circular bioeconomy and contribute to mitigating environmental and climate issues. To start their journey, businesses first need to identify an entry point, evaluate sustainability trade-offs, start small and subsequently scale up, and collaborate with external partners.

To successfully transition to a circular bioeconomy, changes on an isolated micro-level will not be enough. Collaboration is key to successfully integrate circular, bio-based solutions, and active communication is required to foster an open dialogue and shape public opinions. Companies across different industries and value cycle steps must collaborate to understand each other's needs and potentials. For example, feedstock suppliers can play a critical role by producing adequate accessible, sustainable, and cost-competitive renewable resources to enable the bioeconomy to grow. At the same time, they must have a fair income. Brand owners must adjust their business model to give more room and visibility to bio-based products in their product portfolio, including in packaging. In doing so, they can guide customers' choices and influence the entire value chain.

Moreover, additional actors of the economic system must contribute to the required change:

- **Consumers** must adapt their perception concerning bio-based products to allow these solutions to flourish and change from a need to own products toward a desire of using a service.
- **Governments** must continue setting favorable policies for companies active in the circular bioeconomy and could possibly go as far as phasing out regulations supporting fossil-based alternatives.
- **Investors** can contribute in providing the required initial and long-term finance to scale up solutions. Through taking a longer-term perspective, it becomes unavoidable to invest in companies that operate within the regenerative capacity of our planet and that can increase shareholder value in the long-term.

Given the economic opportunity and environmental urgency, this report is a call to action for companies to transition to a circular bioeconomy, with all actors collaborating to enable such a transition.

7 Further resources

7 Further resources

For further information on the circular bioeconomy, please reach out to WBCSD and BCG. BCG's sustainability experts have extensive project experience with clients across the globe.

As a high-level summary to this extensive report for the circular bioeconomy, WBCSD and BCG published the CEO Guide to the Circular Bioeconomy. More details can be found at https://www.wbcsd.org/ceogcbe

BCG conducted a joint study with WBCSD and approximately 100 leading circular bioeconomy companies across industries, resulting in publications such as The New Big Circle, on which more details can be found at https://docs.wbcsd.org/2018/01/The_new_big_circle.pdf

A relevant publication with further insights on bioenergy and biofuels was published by WBCSD's New Energy Solutions project at the COP24 and can be found here: https://docs.wbcsd.org/2018/12/WBCSD_New_Energy_Solutions%20for_1.5C.pdf

On the topic of food loss and waste, BCG published a study on how companies can tackle the challenge here: http://image-src.bcg.com/Images/BCG-Tackling-the-1.6-Billion-Ton-Food-Waste-Crisis-Aug-2018%20%281%29_tcm9-200324.pdf
And collaborated with WBCSD and Sonae on a report here: https://www.bcg.com/en-us/publications/2020/recipe-to-reduce-food-loss-and-waste. You may also consult WBCSD's CEO Guide to Food System Transformation here: https://www.wbcsd.org/Programs/Foodand-Nature/Food-Land-Use/Resources/CEO-Guide-to-Food-System-Transformation.

8 Appendix and references

8.1
KEY DATA POINTS FROM BUSINESS CASE AND INDUSTRY DEEP DIVES

Overview of business case data

Industry	Year	Market size (in USD $ billion)	Market growth p.a. ('18-20')	Biomass (in M tonnes)	Biomass growth p.a. ('18-20')
Total industries	2018	10,330		23,369	
	2030	12,819	1.8%	26,613	1.1%
All industries excluding food end use, incl. food waste	2018	5,730		11,983	
	2030	7,642	2.4%	13,798	1.2%
All industries excluding all food and feed	2018	3,430		6,259	
	2030	5,054	3.3%	7,348	1.4%

Overview of industry specific data

Industry	Year	Market size (in USD $ billion)	Market growth p.a. ('18-20')	Biomass (in M tonnes)	Biomass growth p.a. ('18-20')	Biomass share (in %)
Pharmaceuticals	2018	264		68		21.0%
	2030	760	9.2%	91	2.4%	38.0%
Textiles and wearing apparel	2018	417		119		46.0%
	2030	686	4.1%	185	3.7%	45.0%
Building materials & construction	2018	331		361		3.5%
	2030	682	6.2%	989	8.8%	7.0%
Packaging	2018	375		161		43.0%
	2030	544	3.2%	352	6.8%	44.0%
Motor vehicles & components	2018	255		255		4.6%
	2030	526	6.2%	525	6.2%	5.0%
Other forest products	2018	133		206		27.0%
	2030	201	3.5%	310	3.2%	29.0%
Electronics & electrical products	2018	117		37		5.3%
	2030	217	5.1%	67	5.0%	7.2%
Machinery & equipment	2018	52		34		4.0%
	2030	96	5.3%	58	4.5%	5.5%
Biomass energy & biofuels	2018	143		2,011		9.7%
	2030	188	2.3%	2,419	1.6%	10.5%
Food & feed losses & waste for composting purposes	2018	2,300		5,700		98.0%
	2030	2,590	1.0%	6,400	1.0%	98.0%

REFERENCES

Awasthi et al. (2020). Changes in global trends in food waste composting: Research challenges and opportunities. Bioresource Technology.

BCG. (2018). Tackling the 1.6-billion-ton food loss and waste crisis. Retrieved October 16, 2020 from https://www.bcg.com/publications/2018/tackling-1.6-billion-ton-food-loss-and-waste-crisis

BCG. (2020). Can Delivery Companies Keep Up the E-Commerce Boom? Retrieved October 16, 2020 from https://www.bcg.com/publications/2020/can-delivery-companies-keep-up-with-the-ecommerce-boom

Bill Gates. (2011). Q&A: Bill Gates on the World's Energy Crisis. Retrieved October 19, 2o20 from https://www.wired.com/2011/06/mf-qagates/

Bio Plastics Europe. (2020). What are "bioplastics"? Retrieved October 16, 2020 from https://bioplasticseurope.eu/about

Bioökonomie.de. (2020). Branchen. Retrieved March 15, 2020 from https://biooekonomie.de/sector

Bioökonomierat. (2018). Bioeconomy Policy (Part III) Update Report of National Strategies around the World. Retrieved October 16, 2020 from https://biooekonomierat.de/fileadmin/Publikationen/berichte/GBS_2018_Bioeconomy-Strategies-around-the_World_Part-III.pdf

Brighthouse and BCG. (2016). Purpose: goodpurpose® Study.

Circle Economy. (2018). The circularity gap report.

Circle Economy. (2019). The circularity gap report.

Circle Economy. (2020). The circularity gap report.

Convention on Biological Diversity United Nations. (2011). Nagoya Protocol on access to genetic resources and the fair and equitable sharing of benefits arising from their utilization. Retrieved October 16, 2020 from https://www.cbd.int/abs/

European Commission. (2000). Success stories on composting and separate collection. Retrieved October 16, 2020 from https://ec.europa.eu/environment/waste/publications/pdf/compost_en.pdf

European Commission. (2019). Bioeconomy policy. Retrieved October 16, 2020 from https://ec.europa.eu/research/bioeconomy/index.cfm?pg=policy&lib=strategy

European Commission. (2019). Waste. Retrieved October 16, 2020 from https://ec.europa.eu/environment/waste/construction_demolition.htm

European Commission. (2020). Circular Economy Action Plan. Retrieved October 16, 2020 from https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf

Eurostat. (2020). European Database. Retrieved March 25, 2020 from https://ec.europa.eu/eurostat/fr/home

Food and Agriculture Organization of the United Nations. (2020). Global Forest Resources Assessment 2020 Key findings. Retrieved September 30, 2020 from http://www.fao.org/3/CA8753EN/CA8753EN.pdf

Freedonia. (2020). Global Database. Retrieved February 5, 2020 from http://www.freedoniagroup.com/)

Frost & Sullivan. (2020). Pharmaceuticals and Biotech. Retrieved July 23, 2020 from https://store.frost.com/industries/pharmaceuticals-and-biotech.html

Global Forest Atlas. (2020). Forest Certification. Retrieved October 19, 2020 from https://globalforestatlas.yale.edu/conservation/forest-certification

Grand View Research. (2020). Market research.

Greenhouse Gas Protocol. (2020). Calculation tools. Retrieved March 13, 2020, from https://ghgprotocol.org/calculationg-tools-faq

IEA. (2020). Data and statistics. Retrieved October 16, 2020 from https://www.iea.org/data-and-statistics?country=WORLD&fuel=Energy%20supply&indicator=CoalProdByType

IEA Bioenergy. (2020). Fossil vs biogenic CO2 missions. Retrieved September 30, 2020, from https://www.ieabioenergy.com/iea-publications/faq/woodybiomass/biogenic-co2/

International Council of Forest and Paper Association (ICFPA). (2018). Sustainability Report 2019. Retrieved October 16, 2020 from https://icfpa.org/resources/

Kenniskaarten. (2020). Definition Circular Economy. Retrieved March 23, 2020 from https://kenniskaarten.hetgroenebrein.nl/en/knowledge-map-circular-economy/what-is-the-definition-a-circular-economy/

Nielsen. (2018). Unpacking the sustainability landscape. Retrieved October 15, 2020, from https://www.nielsen.com/us/en/insights/report/2018/unpacking-the-sustainability-landscape

OECD. (2017). Biorefineries models and policy. Retrieved September 30, 2020 from https://www.innovationpolicyplatform.org/www.innovationpolicyplatform.org/oa_folders/toolbox/download/20815/11579/Biorefineries%20Models%20and%20Policies%20%5BDSTI_STP_BNCT(2016)16_FINAL%5D/index.pdf

OECD. (2018). Highlights global material resource outlook to 2060.

OECD. (2019). A fairer, greener, safer tomorrow. Retrieved October 15, 2020 from https://www.oecd.org/development/development-co-operation-report-20747721.htm

Oxford Economics. (2020). Database.

REN21. (2020). Renewables 2020 global status report. Retrieved October 16, 2020 from https://www.ren21.net/gsr-2020/

Schieb et al. (2015). Biorefinery 2030. Springer.

Smithers Pira. (2018). The Future of European Food & Drink Packaging to 2023.

Smithers Pira. (2019). The Future of Bioplastics for Packaging to 2024.

SNE Research. (2020). Market research.

Statista. (2019). Global Statistics.

Stowell, Alison and Hardy, John and Cass, Noel and Stewart, Hilary. (2020). Organic electronics: benefits, barriers and opportunities: A violet biotechnology understanding of organic electronics with a focus on display technology. Lancaster University Management School.

Textile Exchange. (2020). Preferred Fiber & Materials. Retrieved October 16, 2020 from https://textileexchange.org/2020-preferred-fiber-and-materials-market-report-pfmr-released/

U.S. Green Building Council. (2020). Why LEED. Retrieved October 16, 2020 from https://www.worldgbc.org/news-media/bringing-embodied-carbon-upfront

United Nations Economic Commission for Europe. (2020). Carbon Storage in Harvested Wood Products (HWP). Retrieved October 16, 2020 from https://www.unece.org/forests/outlook/carbonstorage.html

United Nations Environment Programme. (2007). Buildings and climate change.

United Nations. (2018). Halting deforestation within reach if we step up action, say UN experts. Retrieved September 30, 2020 from https://www.un.org/development/desa/en/news/forest/halting-deforestation-for-sdgs.html

United Nations' Intergovernmental Panel on Climate Change (IPCC). (2018). Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

Volkswagen. (2019). From the well to the wheel. Retrieved September 30, 2020 from https://www.volkswagenag.com/en/news/stories/2019/04/from-the-well-to-the-wheel.html

WBCSD and BCG. (2018). The new big circle.

WBCSD. (2020). Circular Transition Indicators (CTI). Retrieved October 16, 2020 from https://www.wbcsd.org/Programs/Circular-Economy/Factor-10/Metrics-Measurement/Circular-transition-indicators

WBCSD. (2020). Policy engagement. Retrieved October 15, 2020 from https://www.wbcsd.org/Programs/Circular-Economy/Factor-10/Policy-Engagement

World Green Building Council. (2020). Bringing Embodied Carbon Upfront. Retrieved October 16, 2020 from https://www.worldgbc.org/news-media/bringing-embodied-carbon-upfront

WU Vienna. (2020). Database. Retrieved March 13, 2020 from https://www.wu.ac.at/

WWF. (2020). Biodiversity. Retrieved September 30, 2020 from https://www.worldwildlife.org/pages/what-is-biodiversity

ENDNOTES

[1] Excluding food and feed end use

[2] Circle Economy. (2020). The circularity gap report.

[3] WBCSD has developed the Circular Transition Indicators to help companies measure their circularity. More information on this work here: https://www.wbcsd.org/Programs/Circular-Economy/Factor-10/Metrics-Measurement/Circular-transition-indicators

[4] Circle Economy. (2019). The circularity gap report.

[5] Circle Economy. (2019). The circularity gap report.

[6] WWF. (2020). Biodiversity. Retrieved September 30, 2020 from https://www.worldwildlife.org/pages/what-is-biodiversity

[7] Circle Economy. (2019). The circularity gap report.

[8] United Nations' Intergovernmental Panel on Climate Change (IPCC). (2018). Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

[9] Kenniskaarten. (2020). Definition Circular Economy. Retrieved March 23, 2020 from https://kenniskaarten.hetgroenebrein.nl/en/knowledge-map-circular-economy/what-is-the-definition-a-circular-economy/

[10] If we continue the expected increase in production and keep a GDP growth of 2.8% per year while expecting a decrease in material intensity by 1.3% per year due to structural and economical changes e.g., slowing down in construction boom, then we will be consuming twice the materials as of today, estimated to be 167 billion tonnes in 2060. Circle Economy. (2019). The circularity gap report.

[11] OECD. (2018). Highlights global material resource outlook to 2060.

[12] This number is excluding the actual food and feed consumption

[13] Nielsen. (2018). Unpacking the sustainability landscape. Retrieved October 15, 2020, from https://www.nielsen.com/us/en/insights/report/2018/unpacking-the-sustainability-landscape

[14] Brighthouse and BCG. (2016). Purpose: goodpurpose® Study.

[15] IEA Bioenergy. (2020). Fossil vs biogenic CO2 missions. Retrieved September 30, 2020, from https://www.ieabioenergy.com/iea-publications/faq/woodybiomass/biogenic-co2/

[16] Greenhouse Gas Protocol. (2020). Calculation tools. Retrieved March 13, 2020, from https://ghgprotocol.org/calculationg-tools-faq

[17] Eurostat. (2020). European Database. Retrieved March 25, 2020 from https://ec.europa.eu/eurostat/fr/home; OECD. (2019). A fairer, greener, safer tomorrow. Retrieved October 15, 2020 from https://www.oecd.org/development/development-co-operation-report-20747721.htm; Freedonia. (2020). Global Database. Retrieved February 5, 2020 from http://www.freedoniagroup.com/); WU Vienna. (2020). Database. Retrieved March 13, 2020 from https://www.wu.ac.at/; WBCSD and BCG analysis

[18] Oxford Economics; European commission; WBCSD; BCG analysis

[19] Excluding construction, packaging, and biomaterials from already mentioned industries

[20] Biooekonomie.de; European Commission; Frost & Sullivan; BCG analysis; further read: https://biooekonomie.de/en/branche/pharmaceuticals; https://www.genengnews.com/a-lists/5-biopharma-trends-to-watch-in-2019/

[21] Biooekonomie.de; European Commission; Grand View Research; United Nations; BCG analysis; further read: https://biooekonomie.de/

[22] Although this the actual consumer behavior in some cases, it indicates a clear trend toward sustainable fashion

[23] Textile Exchange. (2020). Preferred Fiber & Materials. Retrieved October 16, 2020 from https://textileexchange.org/2020-preferred-fiber-and-materials-market-report-pfmr-released/

[24] Biooekonomie.de; European Commission; Oxford Economics; BCG analysis; further read: https://biooekonomie.de/

[25] World Green Building Council. (2020). Bringing Embodied Carbon Upfront. Retrieved October 16, 2020 from https://www.worldgbc.org/news-media/bringing-embodied-carbon-upfront

[26] United Nations Environment Programme. (2007). Buildings and climate change.

[27] Circle Economy. (2018). The circularity gap report.

[28] European Commission. (2019). Waste. Retrieved October 16, 2020 from https://ec.europa.eu/environment/waste/construction_demolition.htm

[29] U.S. Green Building Council. (2020). Why LEED. Retrieved October 16, 2020 from https://www.worldgbc.org/news-media/bringing-embodied-carbon-upfront

[30] Biooekonomie.de; European Commission; Oxford Economics; Smithers Pira; BCG analysis; further read: https://www.european-bioplastics.org/

[31] BCG. (2020). Can Delivery Companies Keep Up the E-Commerce Boom? Retrieved October 16, 2020 from https://www.bcg.com/publications/2020/can-delivery-companies-keep-up-with-the-ecommerce-boom

[32] Smithers Pira. (2018). The Future of European Food & Drink Packaging to 2023.

[33] Eurostat; Statista; American Forest & Paper Association; RecyclePaperZA; BCG analysis

[34] Bio Plastics Europe. (2020). What are “bioplastics”? Retrieved October 16, 2020 from https://bioplasticseurope.eu/about

[35] Smithers Pira. (2019). The Future of Bioplastics for Packaging to 2024.

[36] International Council of Forest and Paper Association (ICFPA). (2018). Sustainability Report 2019. Retrieved October 16, 2020 from https://icfpa.org/resources/

[37] ACEA; biooekonomie.de; European Commission; Oxford Economics; BCG analysis; further read; https://docs.european-bioplastics.org/publications/fs/EuBP_FS_Automotive.pdf

[38] Based on a lifecycle assessment of a diesel car. Volkswagen. (2019). From the well to the wheel. Retrieved September 30, 2020 from https://www.volkswagenag.com/en/news/stories/2019/04/from-the-well-to-the-wheel.html

[39] SNE Research. (2020). Market research.

[40] Biooekonomie.de; European Commission; Oxford Economics; BCG analysis; further read: https://biooekonomie.de/en/branche/agriculture-and-forestry; https://biooekonomie.de/der-wald-als-ressource

[41] Food and Agriculture Organization of the United Nations. (2020). Global Forest Resources Assessment 2020 Key findings. Retrieved September 30, 2020 from http://www.fao.org/3/CA8753EN/CA8753EN.pdf

[42] United Nations Economic Commission for Europe. (2020). Carbon Storage in Harvested Wood Products (HWP). Retrieved October 16, 2020 from https://www.unece.org/forests/outlook/carbonstorage.html

[43] Food and Agriculture Organization of the United Nations. (2020). Global Forest Resources Assessment 2020 Key findings. Retrieved September 30, 2020 from http://www.fao.org/3/CA8753EN/CA8753EN.pdf

[44] Global Forest Atlas. (2020). Forest Certification. Retrieved October 19, 2020 from https://globalforestatlas.yale.edu/conservation/forest-certification

[45] United Nations. (2018). Halting deforestation within reach if we step up action, say UN experts. Retrieved September 30, 2020 from https://www.un.org/development/desa/en/news/forest/halting-deforestation-for-sdgs.html

[46] International Council of Forest and Paper Association (ICFPA). (2018). Sustainability Report 2019. Retrieved October 16, 2020 from https://icfpa.org/resources/

[47] Allied Market Research; biooekonomie.de; European Commission; Oxford Economics; United Nations; BCG analysis; further read: https://biooekonomie.de/

[48] Stowell, Alison and Hardy, John and Cass, Noel and Stewart, Hilary. (2020). Organic electronics: benefits, barriers and opportunities: A violet biotechnology understanding of organic electronics with a focus on display technology. Lancaster University Management School.

[49] biooekonomie.de; European Commission; Oxford Economics; BCG analysis; further read: https://biooekonomie.de/

[50] Statista. (2019). Global Statistics.

[51] Schieb et al. (2015). Biorefinery 2030. Springer.

[52] OECD. (2017). Biorefineries models and policy. Retrieved September 30, 2020 from https://www.innovationpolicyplatform.org/www.innovationpolicyplatform.org/oa_folders/toolbox/download/20815/11579/Biorefineries%20Models%20and%20Policies%20%5BDSTI_STP_BNCT(2016)16_FINAL%5D/index.pdf

[53] biooekonomie.de; European Commission; FAO; IEA; Oxford Economics; BCG analysis; further read: https://www.iea.org/fuels-and-technologies/bioenergy

[54] IEA. (2020). Data and statistics. Retrieved October 16, 2020 from https://www.iea.org/data-and-statistics?country=WORLD&fuel=Energy%20supply&indicator=TPESbySource

[55] China National Tobacco Corporation

[56] Philip Morris International

[57] REN21. (2020). Renewables 2020 global status report. Retrieved October 16, 2020 from https://www.ren21.net/gsr-2020/

[58] Awasthi et al. (2020). Changes in global trends in food waste composting: Research challenges and opportunities. Bioresource Technology; European Commission. (2000). Success stories on composting and separate collection. Retrieved October 16, 2020 from https://ec.europa.eu/environment/waste/publications/pdf/compost_en.pdf

[59] BCG. (2018). Tackling the 1.6-billion-ton food loss and waste crisis. Retrieved October 16, 2020 from https://www.bcg.com/publications/2018/tackling-1.6-billion-ton-food-loss-and-waste-crisis

[60] European Commission. (2019). Bioeconomy policy. Retrieved October 16, 2020 from https://ec.europa.eu/research/bioeconomy/index.cfm?pg=policy&lib=strategy

[61] European Commission. (2020). Circular Economy Action Plan. Retrieved October 16, 2020 from https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf

[62] Bioökonomierat. (2018). Bioeconomy Policy (Part III) Update Report of National Strategies around the World. Retrieved October 16, 2020 from https://biooekonomierat.de/fileadmin/Publikationen/berichte/GBS_2018_Bioeconomy-Strategies-around-the_World_Part-III.pdf

[63] Many subsidies remain for fossil fuels and still foster the sourcing and utilization of oil, gas, and coal. Based on the international energy agency (IEA), direct subsidies for the fossil energy fuels coal, oil, and gas, summed up to $320 billion in 2019. Consumers receiving subsidies on average only pay around 85% of the competitive market reference prices. Based on the International Monetary Fund (IMF), direct and indirect subsidies added up eventually end up with an enormous sum of $5.3 billion per year. Indirect subsidies include tax benefits and follow-up costs of energy consumption, especially costs of environmental and health-related damage.

[64] Bill Gates. (2011). Q&A: Bill Gates on the World's Energy Crisis. Retrieved October 19, 2o20 from https://www.wired.com/2011/06/mf-qagates/

[65] WBCSD. (2020). Circular Transition Indicators (CTI). Retrieved October 16, 2020 from https://www.wbcsd.org/Programs/Circular-Economy/Factor-10/Metrics-Measurement/Circular-transition-indicators

[66] Convention on Biological Diversity United Nations. (2011). Nagoya Protocol on access to genetic resources and the fair and equitable sharing of benefits arising from their utilization. Retrieved October 16, 2020 from https://www.cbd.int/abs/

[67] Circle Economy. (2019). The circularity gap report.

ACKNOWLEDGEMENTS

This document is based on analysis by Boston Consulting Group (BCG) and WBCSD from interviews and consultations with WBCSD members that took place between May and October 2020.

We would like to thank the following organizations and people for their valuable contribution to the development of this Roadmap.

CONTRIBUTORS:

Members of WBCSD's Factor10 program: Arcadis, April Group, BASF, Clariant, DSM, GSK, IFF, Neste, Yara

Members of the Forest Solutions Group: Aditya Birla Group, Campbell Global, CMPC, Hancock Natural Resource Group, International Paper Company, Mondi Group, New Forests, Philip Morris International, Smurfit Kappa Group, Stora Enso, Sumitomo Forestry, and the Navigator Company.

Other WBCSD Members: Eni, Mahindra, The Goodyear Tire & Rubber Company

Coordination:

WBCSD: Angela Graham-Brown, Brendan Edgerton, Elena Giotto, Luis Rochartre

BCG: Alexander Meyer zum Felde, Carolin Lanfer, Holger Rubel, Jan Oltmanns, Merle Stepke-Müller

ABOUT BOSTON CONSULTING GROUP

Boston Consulting Group partners with leaders in business and society to tackle their most important challenges and capture their greatest opportunities. BCG was the pioneer in business strategy when it was founded in 1963. Today, we help clients with total transformation—inspiring complex change, enabling organizations to grow, building competitive advantage, and driving bottom-line impact.

To succeed, organizations must blend digital and human capabilities. Our diverse, global teams bring deep industry and functional expertise and a range of perspectives to spark change. BCG delivers solutions through leading-edge management consulting along with technology and design, corporate and digital ventures—and business purpose. We work in a uniquely collaborative model across the firm and throughout all levels of the client organization, generating results that allow our clients to thrive.

WBCSD'S FACTOR 10

Factor10 is WBCSD's circular economy program. It brings companies together to reinvent how business finds, uses, and disposes of the resources and materials that make up global trade. It will bridge the gap between theory and practice to help companies identify and remove barriers and create scalable solutions. It is the global business collaboration delivering innovative, scalable solutions for the circular economy. For more info, please visit https://www.wbcsd.org/Programs/Circular-Economy/Factor-10

THE FOREST SOLUTION GROUP (FSG)

WBCSD's Forest Solutions Group (FSG) is the global platform for the forest sector value chain to build and share business solutions to lead sustainable development in the forest products sector. FSG's mission is to advance the bioeconomy and a thriving forest sector that sustains healthy productive forests and people's well-being. For more info, please visit https://www.wbcsd.org/Sector-Projects/Forest-Solutions-Group

ABOUT WBCSD

WBCSD is a global, CEO-led organization of over 200 leading businesses working together to accelerate the transition to a sustainable world. We help make our member companies more successful and sustainable by focusing on the maximum positive impact for shareholders, the environment and societies.

Our member companies come from all business sectors and all major economies, representing a combined revenue of more than USD $8.5 trillion and 19 million employees. Our global network of almost 70 national business councils gives our members unparalleled reach across the globe. Since 1995, WBCSD has been uniquely positioned to work with member companies along and across value chains to deliver impactful business solutions to the most challenging sustainability issues.

Together, we are the leading voice of business for sustainability: united by our vision of a world where more than 9 billion people are all living well and within the boundaries of our planet, by 2050.

Follow us on Twitter and LinkedIn

www.wbcsd.org

World Business Council for Sustainable Development

Maison de la Paix
Chemin Eugène-Rigot 2B
CP 2075, 1211 Geneva 1
Switzerland
www.wbcsd.org